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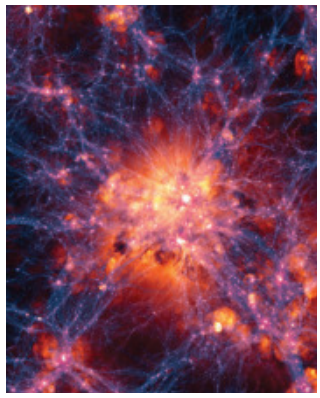

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A cosmic web of galaxy clusters and gas filaments strung between vast voids underpins our universe, as seen in this computer simulation. ILLUSTRIS COLLABORATION

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Picture of the Day
Gorgeous photos from our readers.

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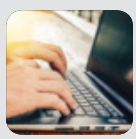
The latest updates from the science and the hobby.



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Enthusiasts connect and share.

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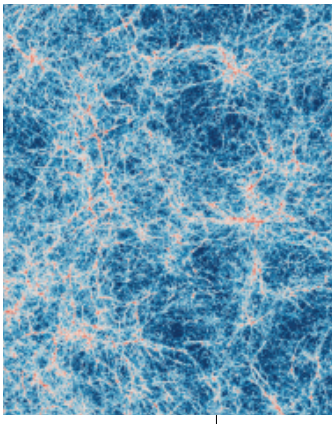
TOP: SOUMYADEEP MUKHERJEE. ONLINE FAVORITES, LEFT TO RIGHT: *ASTRONOMY*: WILLIAM ZUBACK; KPNO/NOIRLAB/NSF/AURA/N. A. SHARP; NASA/JPL/SPACE SCIENCE INSTITUTE; CHINGYUNSONG/DREAMSTIME.COM

Looking ahead



Galaxies and dark matter are arranged across the universe in a web of clusters and filaments, depicted here in a computer simulation. ALEJANDRO BENITEZ-LLAMBAY/UNIVERSITÄT MAILAND-BICOCCA/MPA

When you turn to pages 28 and 29 of this issue, to June's Sky Dome, you may wonder if our printer has gone rogue. It will look as if pages have been printed out of order, with clashing charts and color schemes.

But don't worry — it's deliberate.

Because our July issue will appear only in digital formats, we've rearranged the center of this issue to include July's Star Dome. It's printed on the center sheet, on pages 30 and 31. You can lift it right out of the magazine; printed on the reverse side is July's Paths of the Planets. Once that sheet is removed, you'll see June's full Star Dome occupying the spread below. This is our way of ensuring you don't miss out on a printed star chart for July.

The rest of the July issue will be available to you in all of our digital formats, including our new iOS app and at Astronomy.com.

I know many of you, our loyal readers, will be disappointed to not receive the July issue in a printed format. I understand — today, more than ever, I value holding a physical copy of a magazine and sinking into it, free of distractions. But I'm excited about the digital presentation we're preparing on Astronomy.com, which will showcase stories in ways we haven't been able to before. And our desire to bring you a better print experience is why we'll be refreshing the magazine later this year, with a fresh design that seeks to uphold our original tagline of "the world's most beautiful astronomy magazine."

Meanwhile, the issue you're holding right now contains several features that I'm happy to see on the printed page. Among them is our cover story by Paul Sutter on the cosmic web (page 18) — the skeletal structure of the universe that holds so many of its secrets, including its ultimate fate. On page 40, regular contributor Soumyadeep Mukherjee reports from an astrophotography trip to Kyrgyzstan, with stunning nightscape images. And for when you can't make it to a dark-sky site, Alan Goldstein writes about how you can make the best of light-polluted urban skies (page 46).

I hope you enjoy the issue.

Mark Zastrow
Editor-in-Chief

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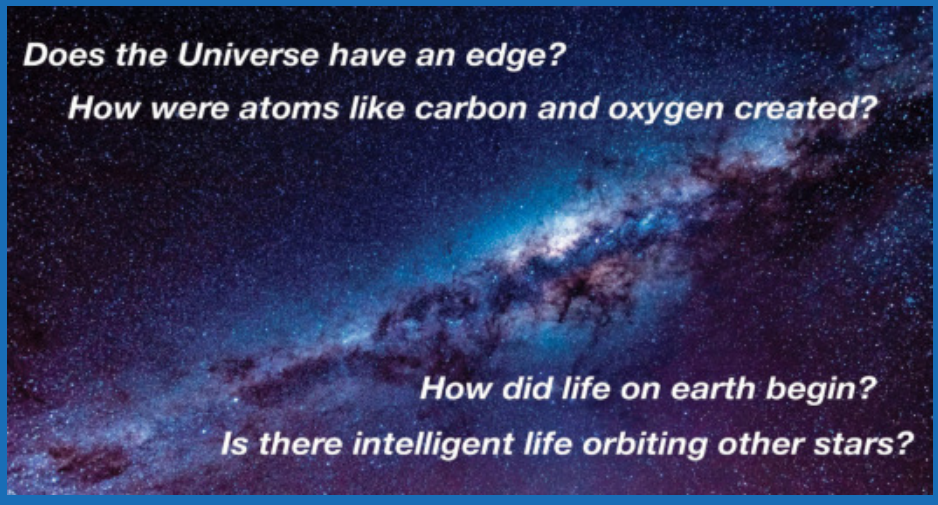
Does the Universe have an edge?
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How did life on earth begin?
Is there intelligent life orbiting other stars?

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9. Enjoying the night sky, galaxy classification, star clusters, active galactic nuclei, and synchrotron radiation.
10. The expanding universe, the Hubble-Lemaitre law, the Cosmological Principle, and dark matter.
11. Special and general relativity, gravitational red shift, black holes, and the cosmic microwave background.
12. Does the universe have an edge? How do we know there was a Big Bang? The universe's age and the universe's fate.
13. Inflation, the 4 forces of nature, string theory, the Anthropic Principle, and women astronomers.
14. Are there extraterrestrial civilizations in the universe? Habitable exoplanets, astrobiology, and K-type star lifetimes.
15. Are there extraterrestrial civilizations on Earth? What is the evidence? Are the witnesses reputable?
16. Review and course highlights.

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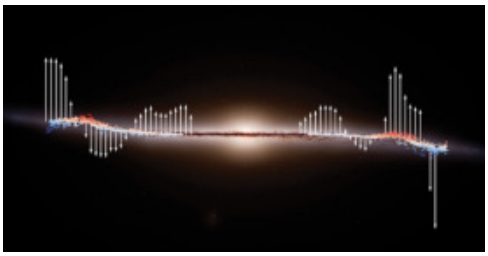

The undulation of the Milky Way's stars, caused by a wave rippling out from the galaxy's center, is illustrated here in a cross-section of the disk. ESA/GAIA/DPAC, S. PAYNE-WARDENAAR, E. POGGIO ET AL (2025)

We welcome your comments via email to **astronomyeditorial@astronomy.com**. *Please include your name, city, state, and country. Letters may be edited for space and clarity.*

A wave of confusion

I read "Gaia sees a great wave" in the AstroNews section of the January issue over and over, and I just don't get it. I can't picture the connection between stars along the warped edge of the galaxy and a wave in a stadium. And the arrows just make matters worse. Do single stars actually rise and fall? Are they moving along the rim, or staying in place? Are they constantly in motion, up and down? At the risk of sounding really dense, please enlighten me. **—Debbie Butler**

Author and staff writer Brooks Mendenhall responds: *The stars are not along the edge of the galaxy, but throughout it. The Milky Way is a rotating, warped disk of stars that wobbles like a spinning top. In the diagram, we are looking at a cross-section of the disk, as if we cut a plate in half and held it up edge-on. From this vantage point, we see that the disk has a single, large-scale wave propagating outward from its center like a ripple in water. The stars, each on their own orbit around the center, bob up and down as the wave passes through them like buoys on the ocean. Because we are talking about long timescales and a really slow wave, the wave (as traced by the stars along it) appears frozen in time, like a photograph of a stadium wave: Some spectators (stars) in the photo are sitting back down, some are just starting to stand, and some are standing all the way up. But it is not moving around the edge like in a stadium.*

The arrows represent the stars' vertical speed. The longest arrows show stars with the fastest vertical motion; they're just starting their journey upwards. Stars already at the crest of the wave can't go any higher and are slowing down, so they have less vertical motion and shorter arrows. Because of this, the wave created by the arrows is offset from the wave made by the positions of the stars.

Errata

In "Watch the Moon turn to blood" (February 2026), an incorrect conversion from Universal Time to Eastern Standard Time caused the times given to be late by one hour. The article also mentioned lunar eclipses occurring at New Moon; they, of course, occur during Full Moon.

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Image: Medusa Nebula taken by Tony Hallas

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SNAPSHOT

HUBBLE CRACKS AN EGG

Short-lived nebula shows off a dying star.

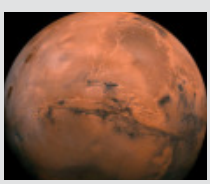
Shining like a cosmic lighthouse, the Egg Nebula is passing through a hard-to-catch phase of stellar evolution. This vast structure of dust and light is created by a Sun-like star in the late stages of its life, as it transitions into a planetary nebula. Glowing within the dust at center is the star; its light reflects off this dust and makes the nebula shine. The arcs, or ripples, visible here are not an image-processing artifact, but concentric shells of material previously ejected by the star in fits and starts. The piercing beams of light highlight faster-moving material shot out from the star's poles.

Known as the preplanetary stage, this period in a star's life lasts only a few thousand years — barely a cosmic eyeblink. The Egg is both the closest and the youngest-known such nebula, offering the best example for astronomers to study. Although not the first image the Hubble Space Telescope has taken of the Egg, this most recent shot offers the clearest view yet, helping astronomers better understand how both the central star and its outflows have evolved over time.

— ALISON KLESMAN

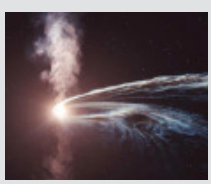
NASA, ESA, BRUCE BALICK (UWASHINGTON). BOTTOM FROM LEFT: NASA/JPL-CALTECH; DESY, SCIENCE COMMUNICATION LAB; RUBINOBS/NOIRLAB/SLAC/NSF/DOE/AURA/H. STOCKEBRAND

HOT BYTES



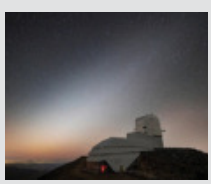
DRYING OUT

New research shows so-called rocket storms on Mars, which quickly send dust high into the atmosphere, can cause the planet to lose water year-round. Previously, scientists thought water loss only occurred when temperatures are hottest for the year.



DEATH OF A STAR

Astronomers calculate that following the tidal disruption event AT2018hyz, in which a black hole shredded an unlucky star, the black hole is now generating a jet with some 1 trillion to 100 trillion times as much energy as the fictional Death Star.

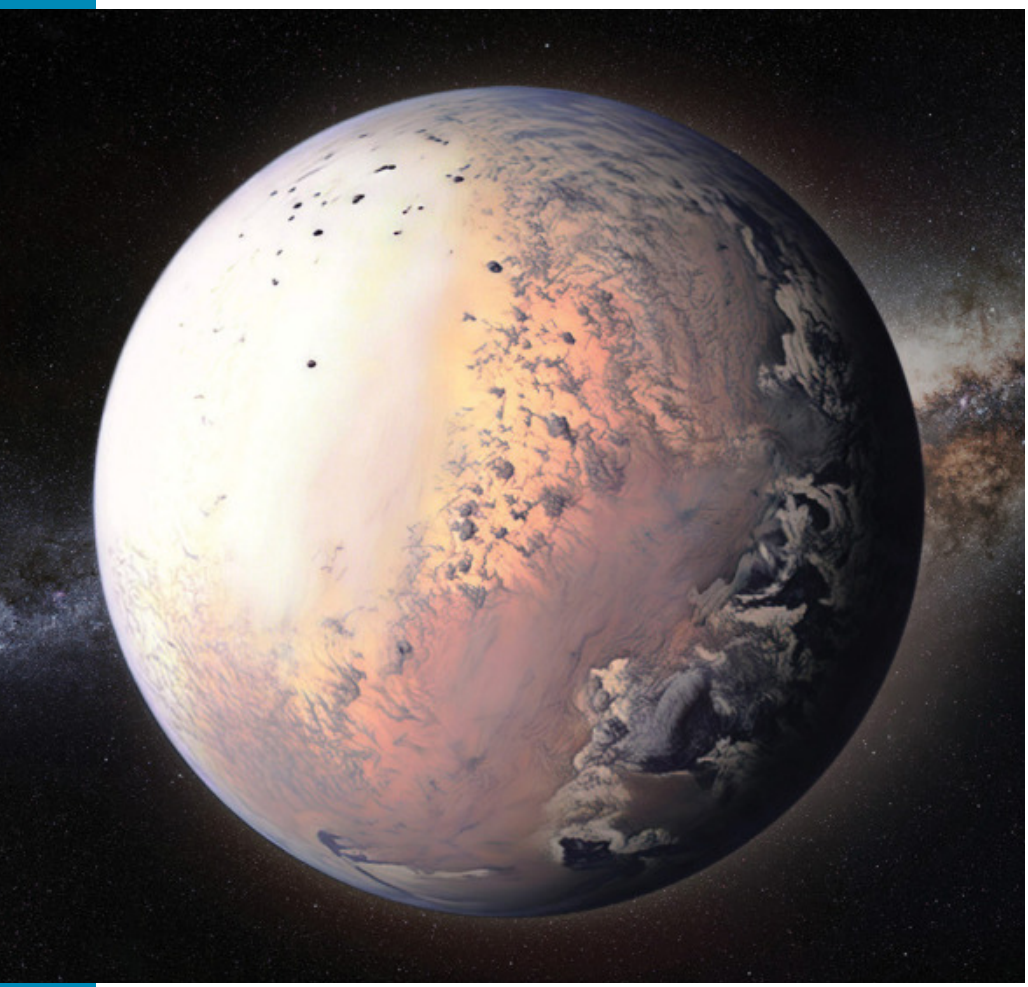


FLOODGATES OPEN

On Feb. 24, the Vera C. Rubin Observatory turned on its main alert system for the first time, issuing 800,000 near-real-time notifications for changes in the sky such as asteroids, supernovae, and more, over the course of a single night.

A PLANET ON THE EDGE OF DESTRUCTION

This rare, fast-orbiting world faces demise at the hands of tidal forces from its star.



RARE PLANET. Ultra-short-period planets, such as the one imagined in this artist's rendering, circle their suns in less than one Earth day. As such, they are very close to their stars, and can be subjected to intense tidal forces. PABLO CARLOS BUDASSI/WIKIMEDIA COMMONS (CC BY-SA 4.0)

» Sixty-six light-years away, an Earth-sized exoplanet completes an orbit in under six hours, at nearly one-hundredth the distance of Mercury from the Sun. Called TOI-6255 b, this planet is on the edge of destruction.

The planet's discovery, led by astronomer Fei Dai of the University of Hawai'i Institute for Astronomy and confirmed using data from NASA's Transiting Exoplanet Survey Satellite (TESS) and the Keck Planet Finder (KPF) spectrometer at the W.M. Keck Observatory in Hawaii, was published in August 2024 in *The Astronomical Journal*.

TUGGED BY TIDES

Tidal forces arise when the gravitational pull from an outside source varies in strength across an object, like when a star pulls harder on the nearside of a planet than its farside. If the planet wanders too close, those forces overcome its structural integrity, ripping it apart. The threshold where this occurs is the Roche limit.

TOI-6255 b orbits just beyond its star's Roche limit. Although complex interactions between the planet and star are causing TOI-6255 b's orbit to decay, it is in no immediate danger — astronomers estimate it won't cross the limit for a few hundred million years. But it is already so close to the star that tidal forces have stretched it from a sphere into an egg.

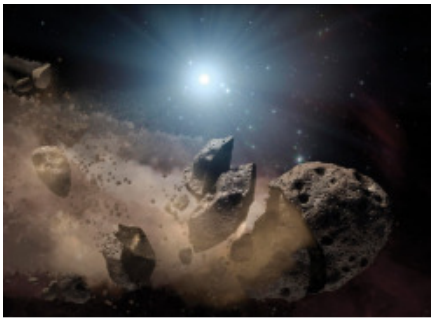
This makes TOI-6255 b a rare opportunity to study how intense tidal forces play out over a planet's surface. Astronomers theorize such interactions could generate signals like radio emission, and hope to use the James Webb Space Telescope (JWST) to look for an atmosphere or potentially study the surface mineralogy.

And while astronomers have found evidence of planets destroyed after crossing the Roche limit, only a few worlds have been found near this precipice. As such, studying TOI-6255 b's composition can also help astronomers determine whether the observed stellar signatures attributed to consumed planets are in fact due to these lost worlds.

TOI-6255 b also has one of the shortest orbits of any known planet, circling its star in just 5.7 Earth hours. Astronomers consider any planet that orbits in less than an Earth day to be an ultra-short-period planet (USP). Of the more than 5,000 confirmed exoplanets, fewer than 150 are USPs, and TOI-6255 b is one of the most extreme. "It's really a very interesting laboratory for probing something that we just don't have in [our] solar system," says study co-author and KPF instrument scientist Sam Halverson of the University of Pennsylvania.

COMBINING FORCES

With so few USPs known, any new



BROKEN UP. If a planet orbits closer to its star than the Roche limit, tidal forces from the star will tear it apart, similar to the way this imagined asteroid is shown disintegrating. NASA/JPL-CALTECH

discovery provides a step toward piecing together how they form, why we don't have any in our solar system, and how rare they really are. But first, astronomers must be able to reliably detect and characterize them.

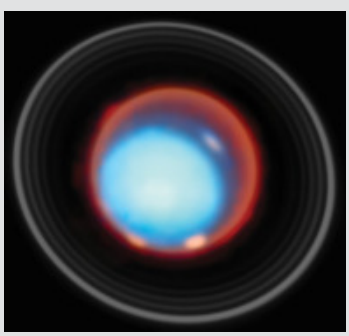
The TESS mission looks at dips in a star's brightness as a planet passes in front of the star, collecting data including the planet's radius and orbital period. The KPF instrument measures how much a star wobbles due to the gravitational pull of an orbiting planet, which reveals the mass of the exoplanet. Dai's study demonstrates how combining TESS and KPF data enables astronomers to determine the densities of exoplanets — as density requires both mass and size to calculate — which can then hint at their composition.

Based on the combined data, TOI-6255 b appears to be a dense, rocky super-Earth the same size as our planet but 1.44 times as massive. Its composition is similar to our planet's as well: likely an iron core some 30 to 40 percent the planet's total mass, surrounded by a silicate mantle.

This combined approach also results in more efficient and cheaper research by using TESS to find planets, including USPs, for KPF to target. "That makes it easier because we're not doing blind searches," Halverson says. And because this combined approach collects the information needed to start sketching out the planet's composition, astronomers will be better able to characterize rare exoplanets like USPs than using KPF or TESS data alone.

For now, TOI-6255 b's extreme example can teach us about both rare planets and the destructive tidal forces they endure — before they are torn apart. — MEGHAN FELDMAN

JWST MAPS URANUS' UPPER ATMOSPHERE



ESA/WEBB, NASA, CSA, STSCI, P. TIRANTI, H. MELIN, M. ZAMANI (ESA/WEBB)

THE ICE GIANT URANUS is a strange world. Its rotation axis is tilted at nearly 98°, so it orbits the Sun on its side. And instead of being aligned with the poles, its magnetic field is tilted 60° from its rotational axis and sits off-center, causing complex aurorae to play through its upper atmosphere. Those aurorae are visible as three small, bright spots in this JWST image. The colors show atmospheric molecules glowing at different heights, with the darkest blue emission originating from heights around 300 miles (500 kilometers) and red from higher levels in the atmosphere, around 3,100 miles (5,000 km). This image is part of a 15-hour-long observation campaign conducted in January 2025 that followed the planet for nearly an entire rotation to understand how energy is distributed in the atmosphere. The data provide the most detailed portrait yet of where Uranus' aurorae form and how they are affected by its tilted magnetic field. The measurements also confirmed that Uranus' upper atmosphere has been steadily cooling for more than 30 years, now averaging a temperature of 310 degrees Fahrenheit (150 degrees Celsius). — B.M.

QUICK TAKES

LIFE'S LEFTOVERS?

A new study suggests that several nonbiological processes scientists have considered thus far can't fully explain the amount of organic material found on Mars by NASA's Curiosity rover in March 2025.

VENUSIAN VOLCANOES

Analyzing archival data from NASA's Magellan, researchers at the University of Trento in Italy have discovered a subsurface lava tube on Venus — a first. The unique opportunity to peer beneath the planet's surface will allow scientists to better understand how it is — and isn't — like Earth or Mars.

JUST PASSING BY

Scientists now believe the observed 200-day-long fading of a star in the constellation Monoceros was caused by the transit of an object with rings 15.8 million miles (25 million km) wide: either a super-Jupiter planet or a brown dwarf.

BIOMINING MICROBES

An International Space Station (ISS) experiment demonstrated some fungi and bacteria can harvest minerals such as palladium from rock in space. The technique could be used to mine asteroids for supplies as humans travel deeper into the solar system.

STARLINER MISHAP

On Feb. 19, NASA released its investigation into the 2024 Boeing Starliner test flight that stranded two astronauts on the ISS for 93 days, calling the incident a "type A mishap" — the same classification applied to the *Columbia* and *Challenger* shuttle disasters.

AI AT THE WHEEL

In February, NASA took a step toward autonomous planetary exploration by using Anthropic's Claude artificial intelligence model to plan a path and successfully pilot the Perseverance rover across 1,500 feet (460 meters) of martian terrain. — BROOKS MENDENHALL

NASA updates Artemis architecture

WAITING ROCKET. A Full Moon shines behind the Artemis 2 Space Launch System rocket on the morning of the mission's Feb. 1 wet dress rehearsal. NASA/SAM LOTT

NASA IS RESHUFFLING the Artemis program, adding a test flight in 2027 as the agency pushes to accelerate its return to the Moon. Artemis 3 was originally slated as a 2028 lunar landing. Now, under the leadership of Jared Isaacman, NASA has moved up its timeline while reducing its scope. Artemis 3 will serve as a low Earth orbit test flight, docking with the SpaceX Starship Human Landing System and potentially Blue Origin's Blue Moon lander, both still under development. Once docked, the crew will test EVA suits, life support systems, and spacecraft propulsion. The first Artemis lunar landing is now scheduled for Artemis 4.

NASA's new approach is more incremental. The agency says it is seeking to advance capability without taking on unnecessary risk. It is also streamlining the Artemis vehicle configuration. Original plans called for increasingly powerful variants of the Space Launch System rocket. Instead, "We want to fly the landing missions in as close to the same Earth ascent configuration as possible," NASA Associate Administrator Amit Kshatriya said in a February news conference.

After Artemis 4, the agency is planning one lunar landing per year — a more aggressive cadence than originally scheduled. Isaacman hopes this will help rebuild NASA's institutional expertise, which he says has eroded over years of slow launch cycles. "When you regain these core competencies, and you start exercising your muscles, your skills do not atrophy," he said. He argues that over-reliance on a web of contractors bogged NASA down with delays and excessive overhead. To fix this, he wants to aggressively hire and embed civil servants alongside industry partners to transfer technical knowledge back to NASA. If all goes to plan, American astronauts will be back on the lunar surface by 2028, aiming for the south pole. —B.M.

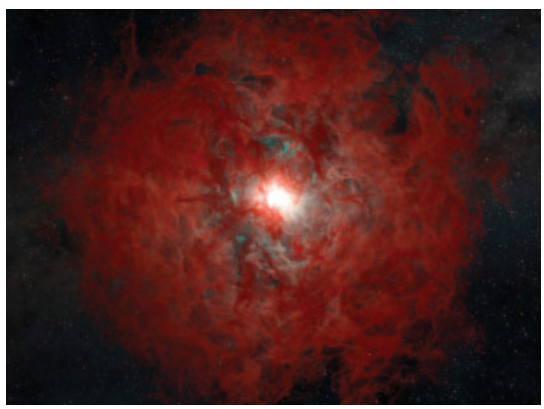
STAR COLLAPSES WITHOUT A BANG

MASSIVE STARS typically die in a supernova: a catastrophic explosion. But M31-2014-DS1, a star 2.5 million light-years away in the Andromeda Galaxy, instead collapsed directly into a black hole. The rare observation, published Feb. 12 in *Science*, is the most detailed to date of a so-called failed supernova.

But there was an important distinction between what stellar evolution theories predicted and how this star behaved. Theories state it should take some 210 days for a star to completely collapse under its own gravity into a black hole. Instead, M31-2014-DS1 faded for more than 1,000 days, suggesting a slower collapse. By examining this behavior alongside a similar oddball star a decade ago, NGC 6946-BH1, the team realized the current theories had overlooked a process at play in stars' outer layers: convection.

As the core collapsed, the gas in the outer layers was still moving rapidly due to convection — the circulation of gas between the star's hotter center and cooler exterior. "This convective material has angular momentum, so it circularizes [orbits] around the black hole," co-author and Flatiron Research Fellow Andrea Antoni said in a press release. "Instead of taking months or a year to fall in, it's taking decades. And because of all this, it becomes a brighter source than it would be otherwise, and we observe a long delay in the dimming of the original star."

The finding suggests that M31-2014-DS1 and NGC 6946-BH1 may not be oddballs after all, but the first in a new class of objects astronomers are just now uncovering. —MICHAEL E. BAKICH



DUSTY SHROUD. After M31-2014-DS1's core collapsed into a black hole (hidden within the glow at center), its outer layers were pushed away rather than being swallowed. This later created a shell of warm dust (red) that stayed visible for years, imagined in this artist's illustration. KEITH MILLER, CALTECH/IPAC - SELAB

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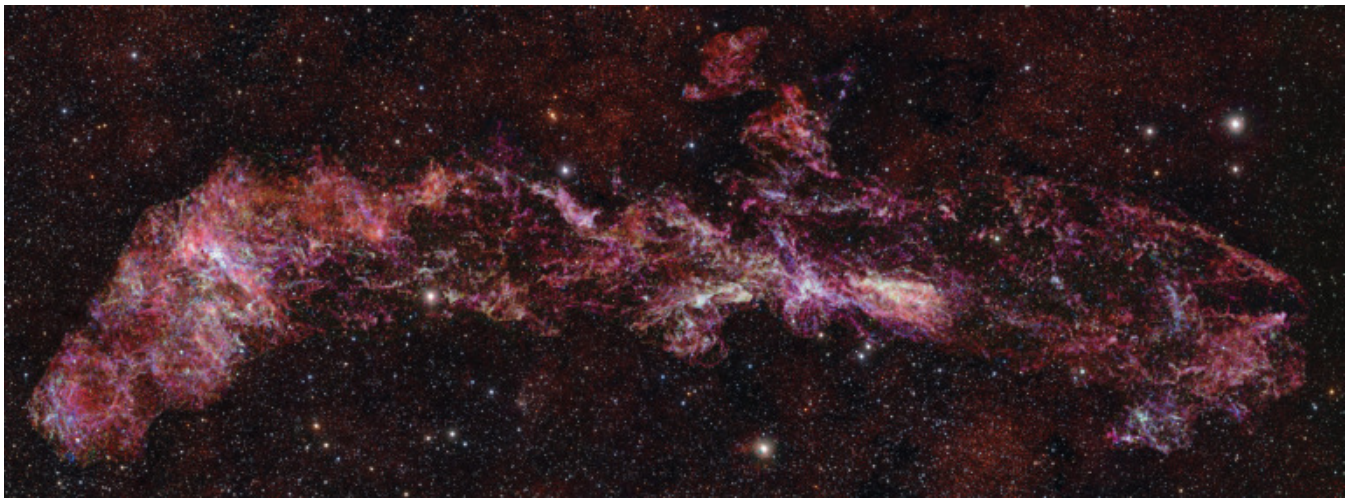

ALMA (ESO/NAOJ/NRAO)/S. LONGMORE ET AL. BACKGROUND: ESO/D. MINNITI ET AL.

LARGEST ALMA IMAGE EVER SHOWS MILKY WAY'S CENTER

THE CENTER OF THE MILKY WAY contains a 700-light-year-wide region called the Central Molecular Zone (CMZ). The CMZ holds nearly 80 percent of all the cold, dense gas in the galaxy — the key ingredient for forming new stars. In addition to many young, massive star clusters, the CMZ also hosts huge flows of supersonic gas, zipping around at hundreds of thousands of miles per hour. This composite of the CMZ is the largest image ever produced by the Atacama Large Millimeter/submillimeter Array (ALMA) radio array in Chile, spanning more than 650 light-years. Each color depicts a different molecule of gas: sulphur monoxide in cyan, silicon monoxide in green, isocyanic acid in red, cyanoacetylene in blue, and carbon monosulphide in magenta. The stars in the image are foreground stars captured in infrared wavelengths; the full density of stars in the CMZ is not shown to keep focus on the structure of the molecular gas. In addition to releasing the new image, the researchers published their data in six papers, accepted by *Monthly Notices of the Royal Astronomical Society.* And a forthcoming upgrade to the ALMA array should improve the view, offering more fine detail and additional chemical information. Astronomers ultimately hope to use the CMZ to better understand not only the Milky Way but also faraway early galaxies, whose stars were formed in similar chaotic conditions. – A.K.

The darkest galaxy yet?

WHEN YOU HEAR THE WORD *GALAXY,* you likely think of a bright, star-filled structure. However, some galaxies are known not for their brilliance, but their darkness. Dark galaxies are composed almost entirely of dark matter with few bright stars, making them extraordinarily difficult to observe. But using the Hubble Space Telescope, scientists recently discovered CDG-2 within the Perseus Cluster, 300 million light-years away. CDG-2 represents the first instance of a galaxy detected by its globular clusters alone — the test case for a new technique that aims to use these bright, concentrated light sources to confirm new dark galaxy candidates. The white circle in this image shows the bounds of CDG-2. Four globular clusters (circled in blue) were the primary signal for the discovery, representing some 16 percent of its visible light. Astronomers estimate that 99 percent of CDG-2's total mass is dark matter, making it one of the most dark-matter-dominated galaxies ever found. – B.M.

NASA, ESA, D. LI (UTORONTO), IMAGE PROCESSING: J. DEPASQUALE (STSCI)

Barry Schellenberg captured IC 1396 with 179 20-minute unguided exposures on a Paramount MX without encoders.

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Left to right: MYT, ME, and MX

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[1]*Five-to-ten-minute unguided exposures are more common.*

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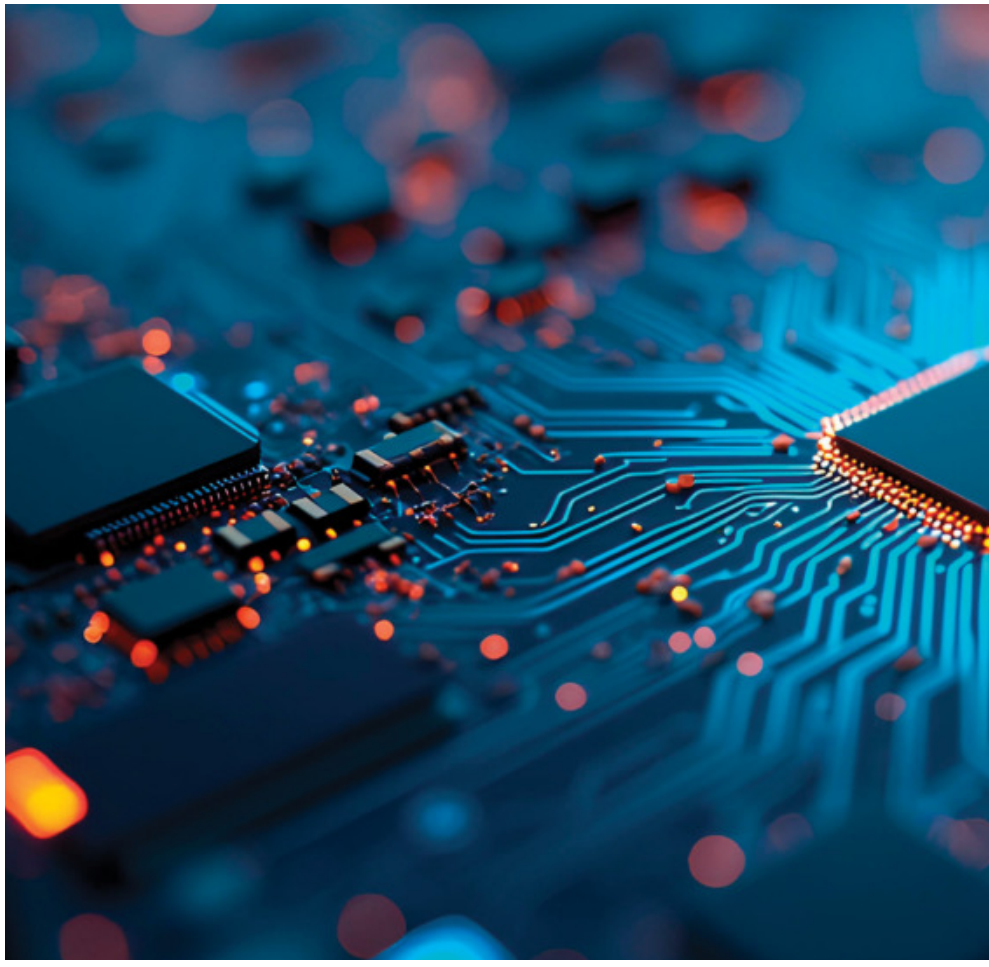


As our dependence on technology grows, even a single particle can disrupt electronics in orbit and on Earth.

BY BROOKS MENDENHALL

OUR PLANET'S ELECTRONIC VULNERABILITY

IN NOVEMBER 2025, Airbus grounded approximately 6,000 of its A320 family of aircraft after an international flight suddenly lost altitude, leading to an emergency landing and the hospitalization of 15 passengers.

In 2003, during a local Belgian election, a candidate received over 4,000 extra votes on a computerized voting machine — more than was physically possible, triggering an investigation.

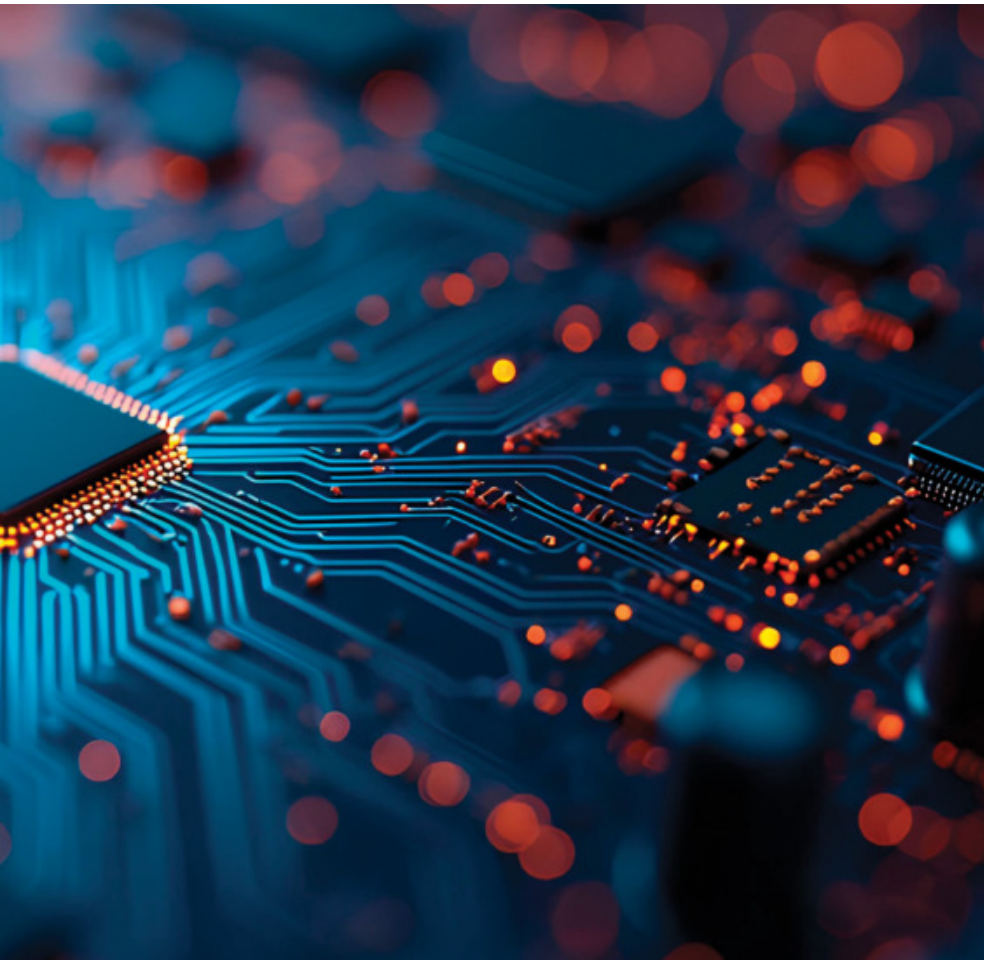
And in a now-famous 2013 incident, two players were speedrunning "Tick Tock Clock," a difficult level on the Nintendo 64 game Super Mario 64, when one player's character shot through the air, skipping a large section of the level and gaining a mysterious advantage over their opponent.

What do these strange, seemingly random events have in common? A bit. Specifically, a computer bit.

The leading explanation for each of these events is what's known as a bit flip: an electronic glitch caused by radiation from space. Although uncommon, they can have significant consequences. And as our reliance on electronics continues to increase, so does our vulnerability to bit flips.

Flipping a bit

Outer space is filled with high-energy radiation: fast-moving particles, such as protons, that constantly bombard Earth. These particles can come from the Sun, but also from deeper space in the form of galactic cosmic rays caused by powerful, distant events like supernovae.



NASSRI/STOCK.ADOBE.COM

While radiation is more likely to affect electronics operating in the harsh environment of space and at high altitudes where Earth's atmosphere is thin, it can also affect ground-based electronics.

Computers store information at its most basic level as bits, electronic units that can have one of two states, corresponding to a value of 0 or 1. A bit flip occurs when a high-energy particle strikes a microchip and quite literally flips one of the chip's bits from 0 to 1, or vice versa. This unintended switch can cause the device to behave in unexpected ways. Typically, bit flips (also known as single-event upsets or SEUs) cause mundane glitches like a frozen screen. Sometimes, though, the glitches can be remarkable or even dangerous, like an airplane suddenly losing altitude, or a voting machine hallucinating thousands of votes.

Process of elimination

What makes bit flips especially insidious is that we often can't confirm one has occurred at all. They are as elusive as they are disruptive. As Bharat Bhuva, professor of electrical and computer engineering at Vanderbilt University, explained in a 2017 Vanderbilt Research News post, "The only way you can determine that [an issue] is a single-event upset is by eliminating all the other possible causes."

In the case of the Super Mario 64 speedrunning incident, informal investigations conducted by the video game community led to the suggestion that a high-energy particle struck the memory location responsible for Mario's vertical position. Flipping a single 1 to a 0 spontaneously increased Mario's height value, teleporting him upward through the floor. A member of the community tested this by intentionally swapping this bit and recording the results. In side-by-side videos, the bit-flipped simulation appears similar to the original glitch.

Yet even with this evidence, there's no way to say for certain a bit flip is to blame. That elusiveness also makes it more difficult for engineers to determine whether their strategies for mitigation are effective, increasing the challenge when it comes to preventing them.

Mitigating the effects

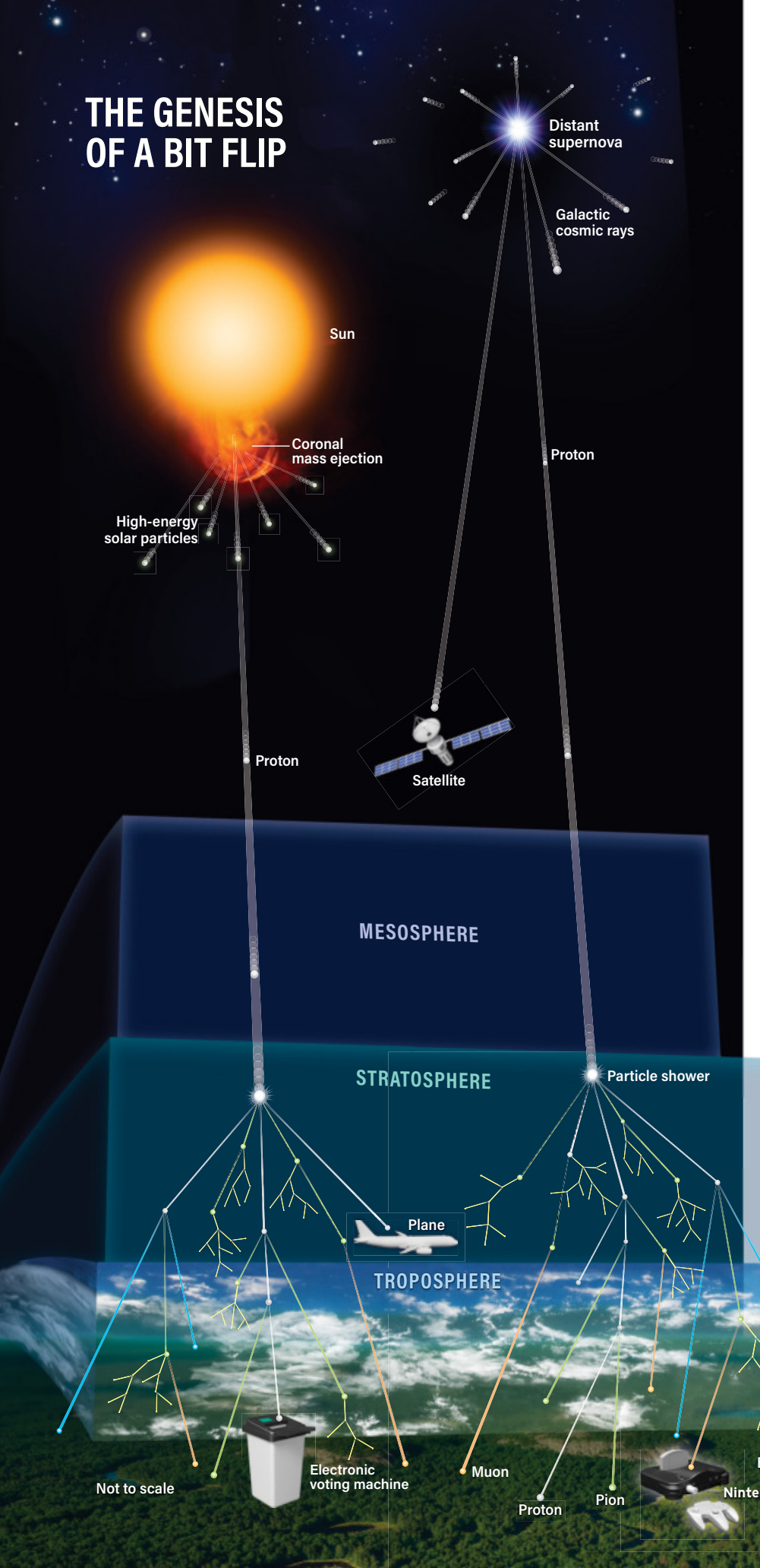
While a video game glitch or a frozen computer screen is relatively inconsequential, radiation can be a serious problem for spacecraft, which operate in high-radiation environments. When reliability is crucial, engineers work to protect electronics from radiation's damaging effects through a process called radiation hardening.

Electronics can be hardened through process, design, and shielding. The specific strategy depends on the environment; for instance, a satellite orbiting Earth faces lower radiation levels than a spacecraft at Jupiter, which must withstand intense radiation produced by that planet's tremendously strong magnetic field. For example, NASA's Europa Clipper, a probe bound for Jupiter's moon Europa, required a purpose-built aluminum vault to shield its electronics and an elongated orbital path designed to minimize radiation exposure — strategies unnecessary for a GPS satellite orbiting Earth.

The oldest mitigation method is radiation hardening by process (RHBP), in which fabricators construct chips from materials that make them more resistant to radiation. For example, rather than building chips on standard silicon, fabricators use insulating substrates like sapphire to prevent radiation-generated charge from spreading through the chip. Fabricators also carefully introduce small amounts of impurities into the silicon — a process called doping — to reduce how much charge a particle strike can generate.

The idea behind RHBP is to embed radiation resistance into the physical properties of the chip itself. However, "[RHBP] technologies tend to serve niche, low-volume markets, and the manufacturing expense and specialized supply-chain requirements make RHBP integrated circuits very expensive," says Brian Sierawski, professor and interim director of the Institute for Space and Defense Electronics (ISDE) at Vanderbilt University.

A lower-cost alternative is radiation hardening by design (RHBD), which foregoes specialized materials and instead modifies how the circuits are



Galactic cosmic rays constantly bombard Earth — striking us and our devices tens of billions of times each day. The Sun also constantly emits charged particles, but more rarely do they contain energies similar to cosmic rays. When a high-energy proton strikes a particle in Earth's atmosphere, it triggers a cascade of smaller subatomic particles, such as neutrons, muons, pions, and neutrinos, that can disrupt electronics. *ASTRONOMY:* ROEN KELLY

structured and arranged. Designers might, for example, "make transistors different sizes or shapes ... add in circuit redundancy ... or come up with a clever circuit design," Sierawski says.

One common RHBD approach in spacecraft is triple modular redundancy, where three separate circuits perform the same calculation and vote on the result. For example, on NASA's Perseverance Mars rover, three copies of each instrument circuit are installed so that if one is struck by a particle, the other two override it.

Perhaps the most intuitive approach is radiation hardening by packaging, also called shielding. This involves putting heavy material between the electronics and the radiation in an attempt to keep the radiation out. This is the function of Europa Clipper's aluminum vault — designed to absorb enough of Jupiter's intense radiation to keep the spacecraft's electronics operating.

"People less familiar with radiation will typically say, 'Let's just shield it,'" ISDE associate director Michael Alles says. The problem, he explains, "comes down to mass." Shielding requires placing components in radiation-resistant materials like lead or tungsten, which are heavy and not always practical for launching into space.

It's not all bad news for shielding. According to Sierawski, there is a lot of low-energy radiation in space that can be blocked by shielding. "By using some shielding, you . . . knock down that lower energy so it doesn't actually reach your electronics," he says.

However, the technique does come with diminishing returns: "Once you get to a point where you're just adding

mass and you're not able to actually stop the rest of the environment, that's just a cost to the system," he says.

Closer to home

While radiation hardening is often associated with spacecraft, the effects of bit flips are also felt on Earth. At cruising altitude, aircraft flight computers are exposed to elevated radiation levels. To combat this exposure, airplane computers employ an RHBD technique called dissimilar redundancy, which uses flight computer hardware and software architectures from different manufacturers to ensure a single-event upset doesn't affect all systems simultaneously.

In the 2025 Airbus incident, engineers determined the accident was most likely the result of a bit flip in the plane's Elevator Aileron Computers (ELACs) — the systems responsible for pitch and roll. "Analysis of a recent event involving an A320 Family aircraft has revealed that intense solar radiation may corrupt data critical to the functioning of flight controls," the company wrote in a Nov. 28 press release.

The affected computers have dissimilar redundancies in place to mitigate this sort of error. The A320 employs multiple independent flight control computers: two ELACs and three Spoiler Elevator Computers. Similar to triple modular redundancy, these units constantly cross-check each other's calculations. If one computer generates a command that disagrees with the others, the system is designed to vote it out and ignore the erroneous data.

The solution deployed by Airbus was to roll back all A320 ELACs to a previous version. For most of the fleet, this meant a simple software swap; for some planes, entire computers were replaced. As Alles notes, "the [bit flip] is still likely happening in the hardware, but it's how the software is communicating" that determines the outcome. It's possible that a software update introduced a flaw that overrode the flight computer's dissimilar redundancy, requiring a fallback to proven code.

The incident speaks to the elusive nature of bit flips — and to how vast the threat really is. It's difficult to say for certain whether a bit flip was to blame, why the redundancies failed, or even where the offending particle came from.

Researchers at the University of Surrey's Space Centre questioned Airbus' claim of solar radiation, noting the aircraft would have experienced normal radiation levels that day. Matthew Owens, a professor of space physics at the University of Reading, adds that "there was no space weather of note on Oct. 30." This raises the possibility that the culprit was a galactic cosmic ray, rather than a solar particle — a reminder that the threat does not end at the edge of our solar system.

'Hardening by serendipity'

The Airbus incident underscores the importance of hardening in applications where a bit flip can put lives at risk. But in many other applications, that level of rigor is being set aside.

Traditionally, space agencies developed specialized electronic components for space applications, meaning that commercial off-the-shelf components — like the inexpensive chips found in modern smartphones — were off-limits. The rapid expansion of commercial spaceflight is forcing a rethink of this approach. As costs mount, Alles says a new philosophy is emerging, one he calls "hardening by serendipity."

Rather than engineering out the risk, companies accept it. A company might launch a constellation of satellites knowing that 10 to 20 percent will fail, Alles says, simply rerouting data through functioning neighbors when one goes down. "They don't care about that one big thing they got to get right like NASA always did," he says.

The consequences of this shift are felt on Earth: As radiation-vulnerable commercial components become the backbone of global infrastructure, bit flips and other radiation effects may become a routine cost of doing business. And when satellites do fail, deorbiting hardware burns up in the atmosphere, contributing to a growing problem of atmospheric pollution. It is a philosophy born of cost, whose consequences may be felt beyond the satellite industry.

As modern consumer electronics scale down, the possibility of radiation effects becomes a game of trade-offs. While smaller transistors present a smaller target for a passing particle, they also allow for higher component density — meaning that even if an individual bit is less likely to be hit, there are more bits available to be struck. The problem can't be solved by simply making chips increasingly smaller; instead, it requires new ways of managing risk.

Whether the consequences range from trivial gaming glitches to critical aviation failures, the underlying physics of bit flips remains the same. As we grow more dependent on electronics on Earth, fill the skies with satellite constellations, and set our sights on a permanent human presence beyond our planet, managing these events is no longer a specialized task for space agencies, but a basic requirement for the reliability of the global digital infrastructure.

Brooks Mendenhall *is a staff writer for* Astronomy *and is based in Chattanooga, Tennessee.*

TRANSIENT VERSUS CUMULATIVE EFFECTS

Bit flips fall into the broader category of transient radiation effects. Transient effects are random occurrences: "the result of a single particle that happens to be in the right place at the right time," says Brian Sierawski. The damage from single-event upsets is generally temporary and reversible. Other transient radiation effects are not. Single-event burnouts, for example, occur when a striking particle doesn't just flip a bit. Instead, "a power transistor [a switch that controls current and voltage] gets hit by an ion [a charged particle] of some sort, and it burns out. It ceases to function," explains Michael Alles.

Electronics are also susceptible to cumulative radiation effects — particularly electronics in high-radiation environments like space. The total ionizing dose (TID) is the total amount of radiation that a component will be exposed to over time. Unlike the sudden hit-and-run nature of transient effects, TID is a slow buildup of radiation damage over time. This can lead to parametric degradation, where components gradually function less and less efficiently. Eventually, this degradation results in the total failure of the component.

UNTANGLING THE COSMIC WEB

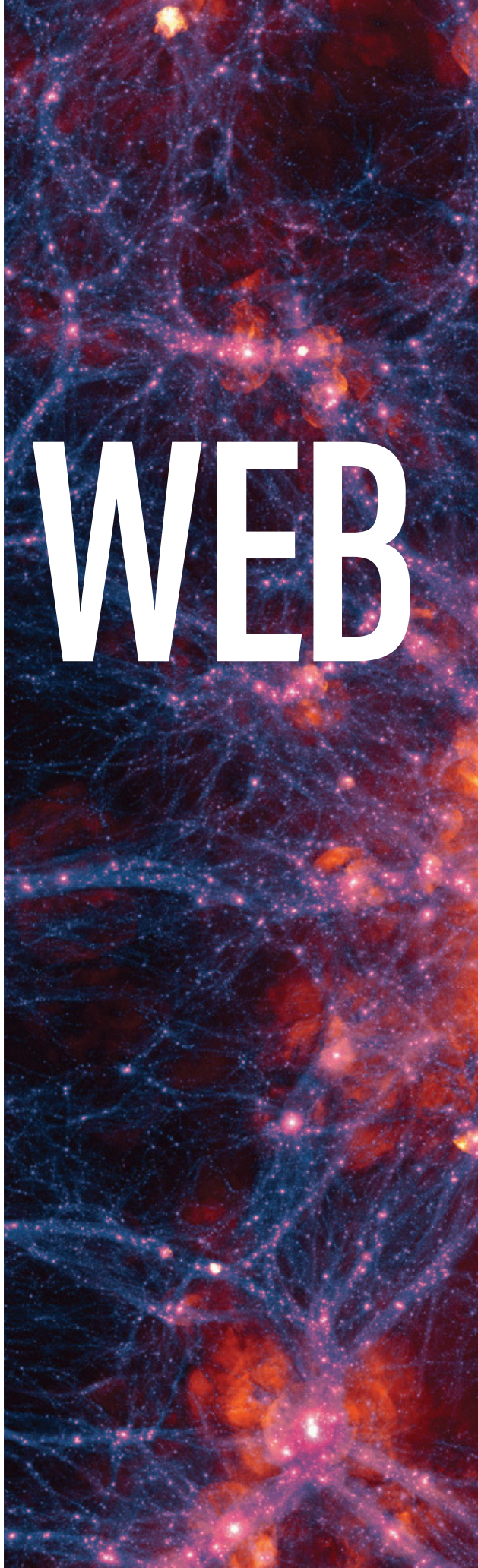
From filaments and voids to superclusters of galaxies, astronomers are reading the blueprint of the universe. BY PAUL SUTTER

THERE IS A PATTERN found in nature. It is indeed the largest pattern there is. It is so vast that it spans the universe, filling up its observable volume. The pattern is made of individual units in the same way your body is made of cells — if each of your cells were a galaxy with hundreds of billions of suns.

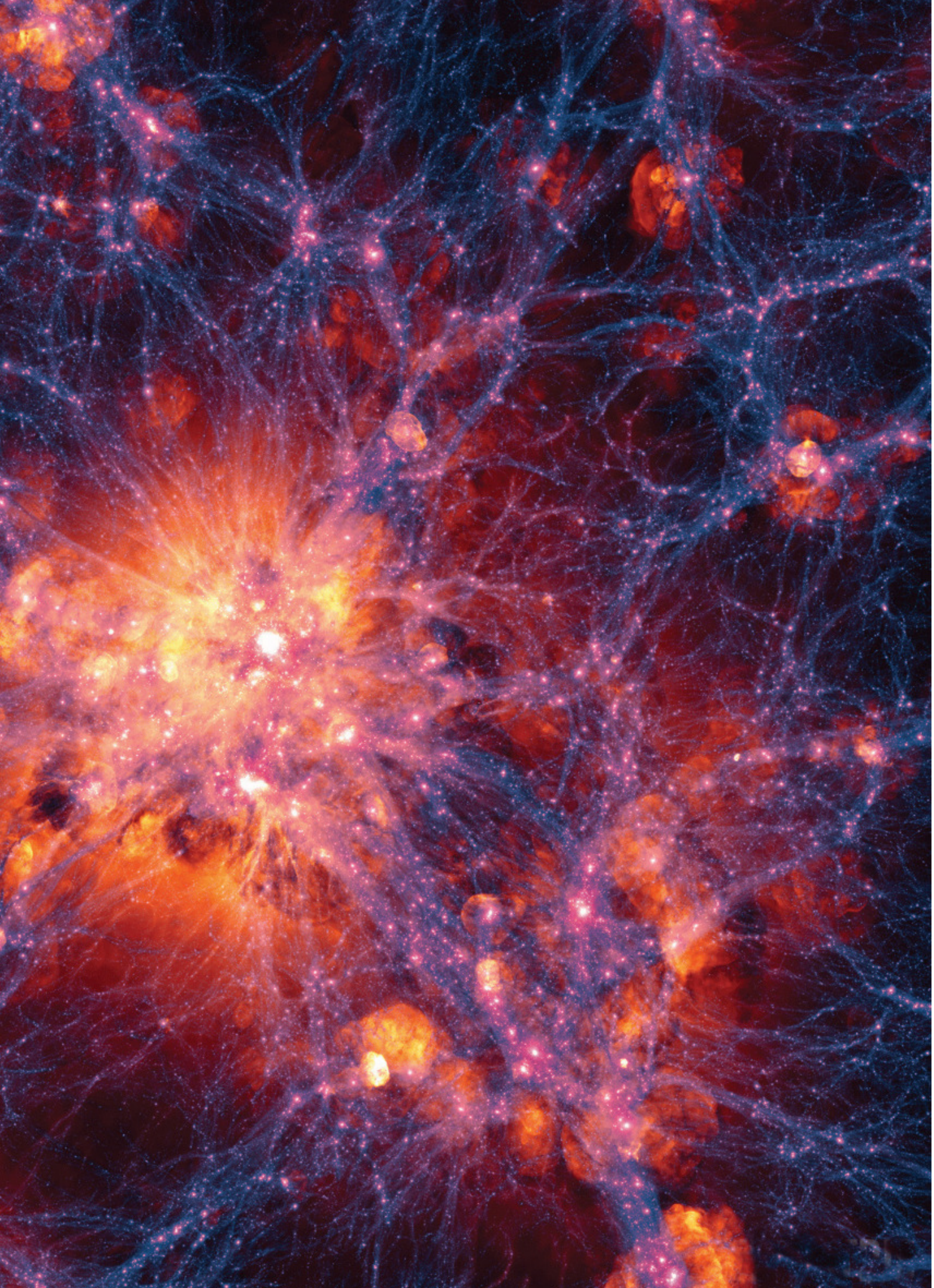
This pattern is the cosmic web, and it holds the secrets to the fate of the entire universe.

The web is caught between two opposing forces, which happen to be the two great cosmological mysteries of our time: dark matter and dark energy. The invisible pull of dark matter helped assemble the cosmic web. Dark energy threatens to tear it apart.

After nearly a century of effort, we have mapped and studied less than a percent of all the galaxies in the observable universe, which spans a diameter of more than 90 billion light-years. But even with that slim effort, we have traced out the fundamental components of the cosmic web. There are the tight, dense clumps, known as galaxy clusters, where thousands of galaxies are packed within relatively compact regions of around a few million light-years. There are also long, thin filaments stretching for millions of light-years that connect those clusters. And then there are giant, two-dimensional walls, like sheets of galaxies billowing in the cosmic web. Finally there are the voids, vast regions of almost nothing, the great cosmic deserts that



A galaxy cluster is threaded by tendrils of dark matter (blue-purple) in this still frame from a computer simulation. The red, orange, and white bubbles depict hot gas, heated by supernovae or jets from supermassive black holes. ILLUSTRIS COLLABORATION



make up most of the volume of the universe.

Extensive surveys have revealed, and even named, portions of the nearby cosmic web. The Milky Way, our nearest neighbor the Andromeda Galaxy (M31), and the Triangulum Galaxy (M33) make up the major members of the Local Group, a clump of galaxies bound together by mutual gravity.

The nearest cluster to us is Virgo, which contains roughly 2,000 galaxies, sitting about 65 million light-years away. Along with every other member of the Local Group, we're headed toward the Virgo Cluster, pulled by its enormous gravity outweighing that of a thousand trillion Suns.

The Virgo Cluster is itself a member of a long filamentary branch known as the Virgo Supercluster. But that branch is just one piece of a much larger structure, called the Laniakea Supercluster, taken from the Hawaiian word for "bountiful heaven." It's an immense assembly of millions of galaxies twisting and winding its way through more than a hundred million light-years of the cosmos.

Between all of these grand structures are the nearby voids. One of them, the Boötes Void, measures 300 million light-years across. It does contain some dim, faint galaxies, the way that an oasis can spring up even in the deepest deserts, but otherwise it's almost entirely empty of matter.

The cosmic web, with all of this complexity, has not always been here. It took billions of years to evolve, and it's in that evolution that we find the keys to the universe's fate.

Assembly required

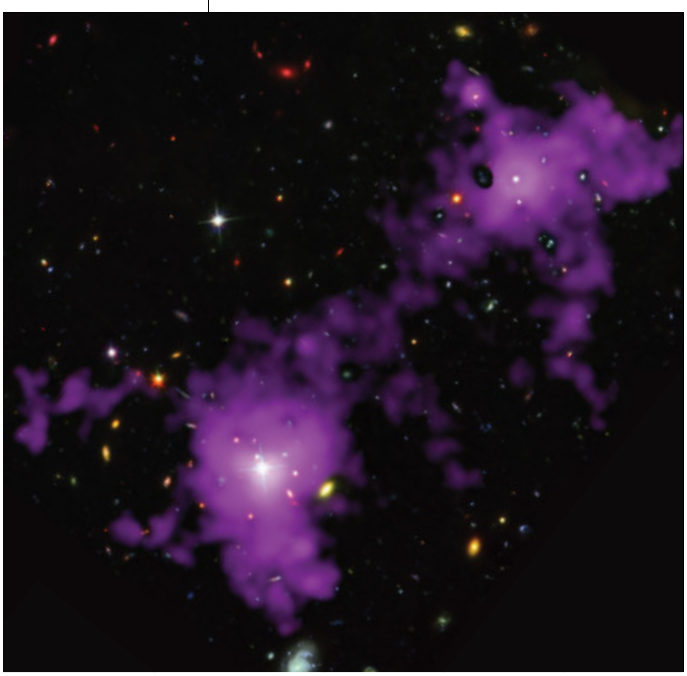
In the early universe, matter was much more uniform. There were no great density variations from place to place. But there were tiny differences, laid down in the earliest moments of the Big Bang, that served as seeds of what was to come. As time went on, gravity did its work, pulling more and more material onto those tiny seeds. As they grew, they became greedy, reaching out even farther to attract more matter.

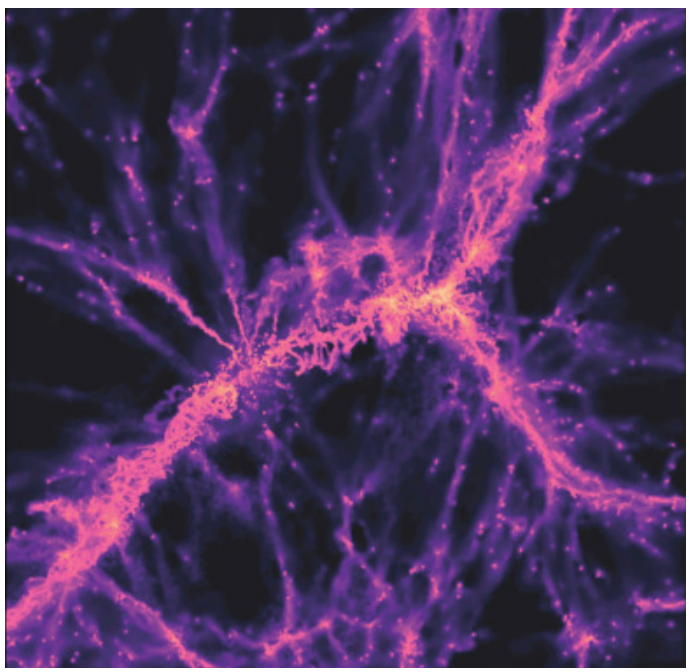
Over hundreds of millions of years, the rich got richer and the poor got poorer. First came the galaxies, then the groups. Then groups assembled into clusters. The walls and filaments condensed. And the first voids appeared, the cosmic quarries that had been mined for material to build the cosmic web.

The properties, structure, and evolution of the cosmic web are intimately tied to the fundamental laws and parameters that govern the universe. If the cosmos followed different rules or was made of other kinds of material, then the present-day cosmic web would be entirely different.

Today we know that the vast majority of the universe, around 95 percent, is of a form unknown to modern physics. All of the ordinary matter and light that we know makes up only a tiny portion of the cosmos. The next largest chunk, comprising around 25 percent of all the stuff in the universe, is dark matter, a form of matter that is invisible, emitting no light. The remainder is dark energy, the unknown force that appears to be accelerating the expansion of the universe.

Regular matter, dark matter, and dark energy all have a hand in building the cosmic web. Indeed, we only ever get to see a slim portion of the true cosmic web, even with our most comprehensive galaxy surveys. That's because most of the web is dark matter. Like





BELOW LEFT: It isn't easy to capture direct images of the cosmic web, but over the course of 150 hours of observations, the Very Large Telescope snapped this shot of a filament (purple) stretching for 3 million light-years between two galaxies, seen just 2 billion years after the Big Bang. The background image was taken by the Hubble Space Telescope. ESO/D. TORNOTTI ET AL./HUBBLE: M. REVALSKI, P. FRANCIS ET AL.

BELOW RIGHT: A virtual twin of the observed filament is shown in a still from a supercomputer simulation. DAVIDE TORNOTTI/UNIVERSITY OF MILANO-BICOCCA/MPA

lighthouses twinkling on a distant shore, the galaxies act as tracers of where the true concentrations of matter really are. Dark matter serves as the bones of the cosmic web and, through its gravitational influence, allows for galaxies to form in its densest regions.

On the other hand, dark energy is tearing the cosmos apart. The mysterious accelerated expansion first made its presence felt about 5 billion years ago. It's weak, just a gentle push on the natural expansion of the universe. But it's relentless, and it shows no signs of stopping anytime soon.

This effect overwhelms gravitational attraction at large scales. Our Local Group will stay intact, our bonds of gravity strong enough to resist accelerated expansion. But we will never reach the Virgo Cluster. Sometime from now, likely billions of years in the future, our headlong rush toward that cluster will slow to a crawl, stop, and reverse, forever remaining tantalizingly out of reach.

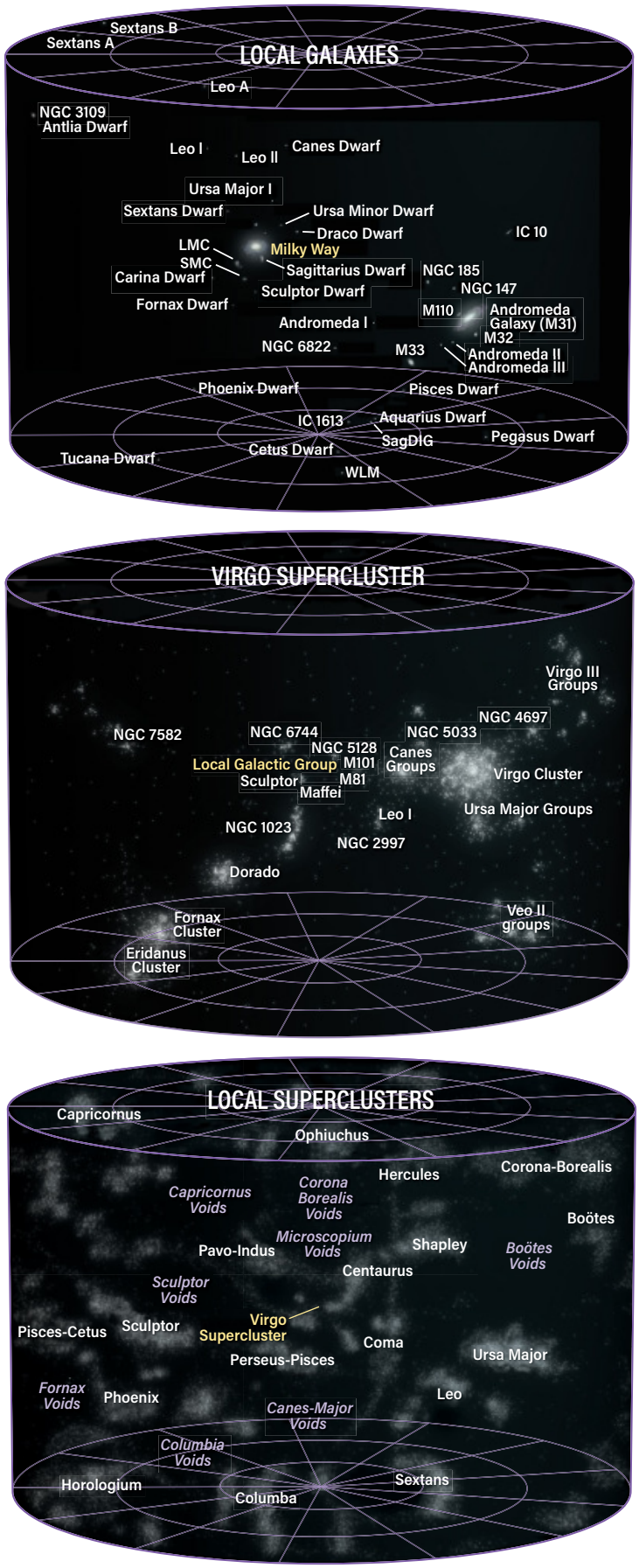
The fate of the universe

The Virgo, Laniakea, and every other large supercluster will not last much longer. Eventually the entire cosmic web will disintegrate. What the universe took billions of years to construct will eventually dissolve.

This is why the cosmic web is so crucial to our understanding of the makeup of the universe: the present-day arrangement of galaxies sits on the transition point between the building efforts of dark matter and the destructive effects of dark energy. The more we can learn about the cosmic web, the more we can learn about the hidden, dark side of the cosmos.

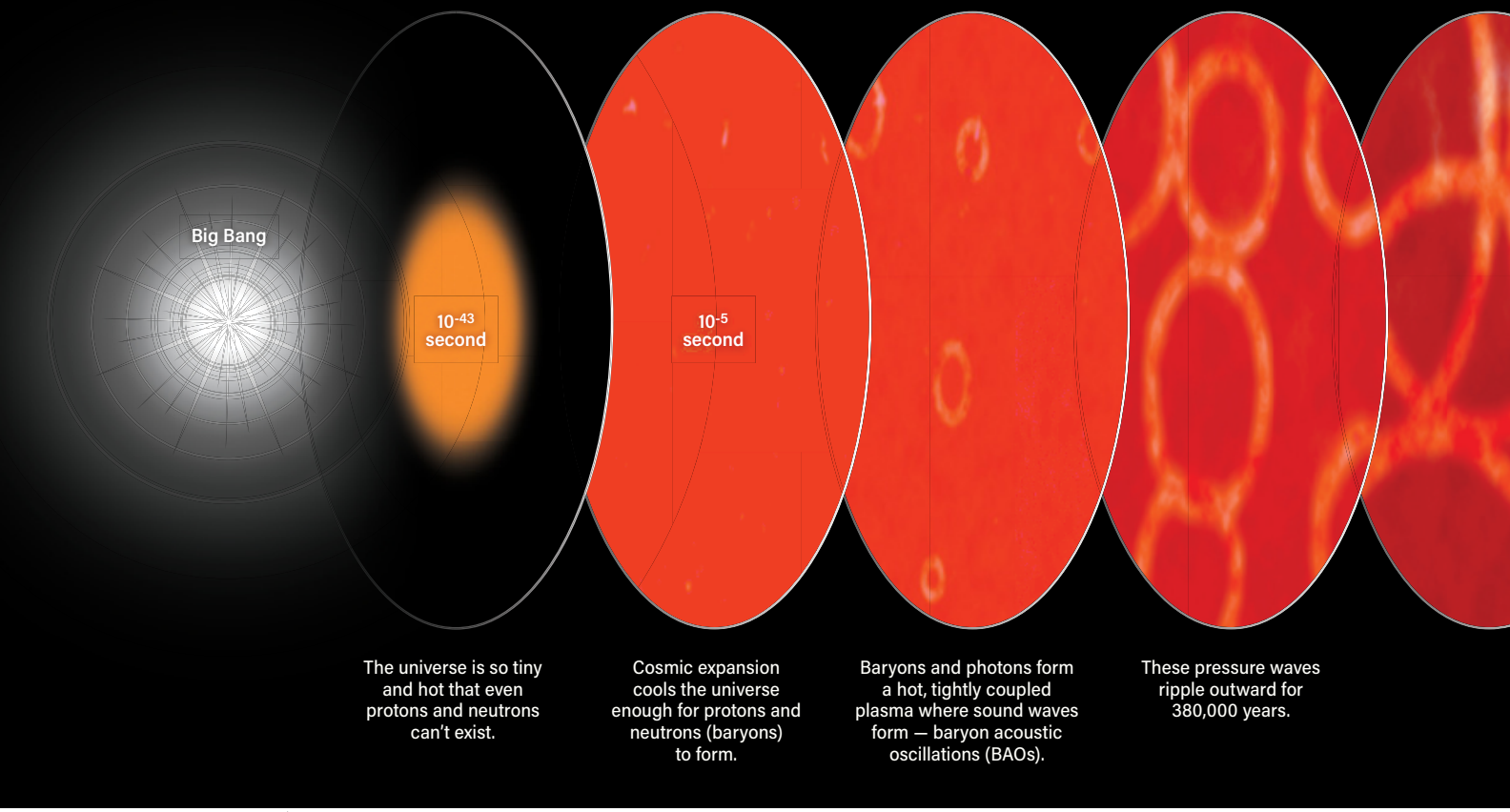
In April 2025, the Dark Energy Spectroscopic Instrument (DESI) collaboration released a shocking new result after years of careful analysis. Perched atop Kitt Peak in southeastern Arizona, the 4-meter telescope has spent the past several years amassing detailed measurements of more than 13 million galaxies. The survey is only about a

OUR PLACE IN THE WEB



To see the cosmic web, you have to zoom out to scales of hundreds of millions of light-years across. The Milky Way lies inside the Local Group of galaxies (top), spanning tens of millions of light-years. Zoom a bit farther out (middle) and the Local Group is visible as part of the Virgo Supercluster, one node of the cosmic web spanning roughly 100 million light-years (middle). By the time we zoom out to a view roughly 1 billion light-years across, the structure of the cosmic web emerges clearly, with superclusters aligned in strands and filaments, separated by cosmic voids.

ANDREW Z. COLVIN/WIKIMEDIA COMMONS/CC BY-SA 3.0


ANCIENT SOUNDS IN THE COSMIC WEB
Big Bang
10-43 second
10-5 second
The universe is so tiny and hot that even protons and neutrons can't exist.
Cosmic expansion cools the universe enough for protons and neutrons (baryons) to form.
Baryons and photons form a hot, tightly coupled plasma where sound waves form — baryon acoustic oscillations (BAOs).
These pressure waves ripple outward for 380,000 years.

Some of the structure of the cosmic web can be traced back to sound waves propagating through the early universe — when the cosmos was much smaller and denser. *ASTRONOMY:* ROEN KELLY

quarter through its planned set of targets, but it's already found something curious.

In addition to the familiar structures of the cosmic web like clusters and filaments, there is another signature imprinted on the cosmos in the form of baryon acoustic oscillations, or BAOs. The BAOs were created in the first few hundred thousand years after the Big Bang, when the universe was so compact that matter and light couldn't separate, locked together in a hot soup of plasma dense enough for sound waves to crash through it. But once the plasma cooled and became neutral, the light broke free from the matter, and the sound waves froze in place.

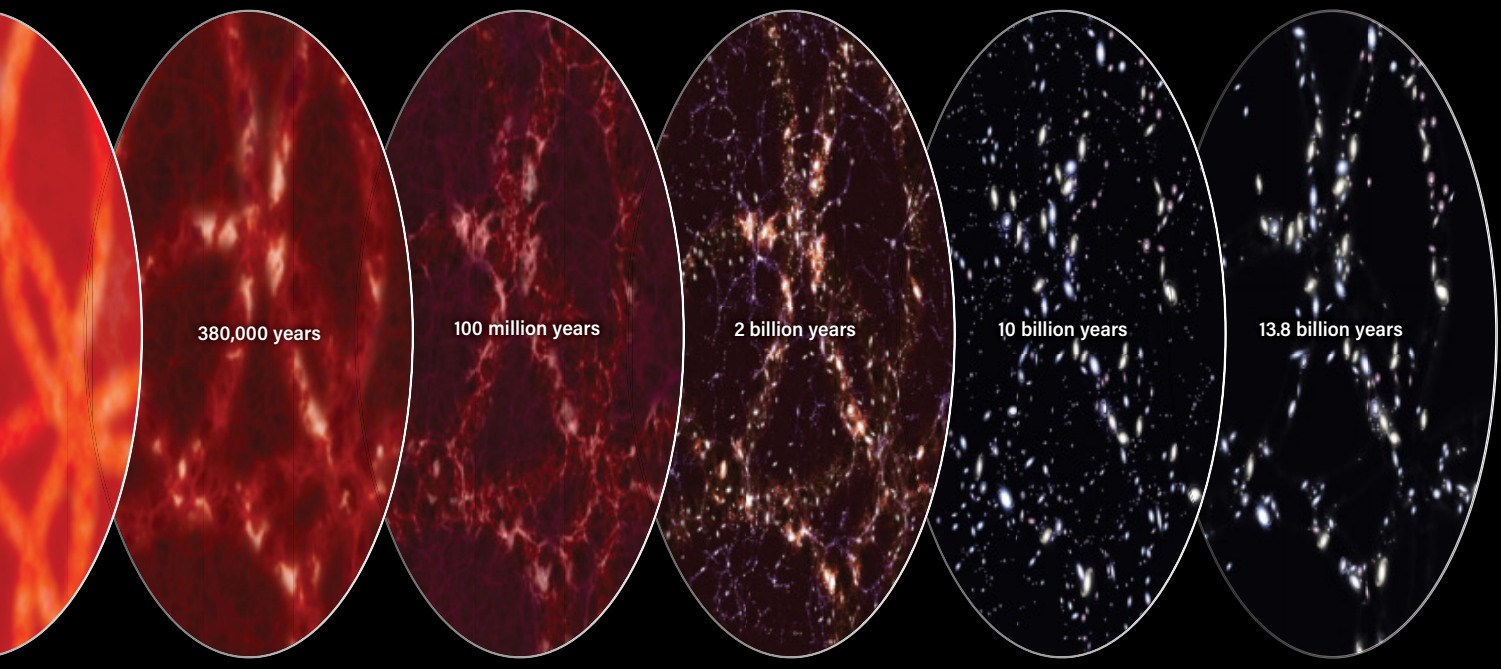
Like a snapshot captured right after a snare drum's been struck, the resonant shells of compressed matter stayed where they were. These locations acted as a source of extra gravitational attraction. Billions of years later, the BAOs show up in our galaxy surveys as regions of slightly higher density than average, embedded within the larger cosmic web.

BAOs are critical to modern cosmology because they are what's known as a standard ruler. We know how big they're supposed to be, thanks to the physics of sound waves and our precise measurements of the cosmic microwave background (CMB) — the light released at the moment the universe cooled from a plasma to a neutral gas. Put them together, and the predicted size of the BAO shells falls out: about a billion light-years in diameter. By comparing those predictions to how big they actually appear, we can tease out the evolution of the universe by mapping the expansion rate at various points in time, like marking the height of a child on your door frame through the years.

DESI's latest analysis of BAO data, published in 2025, suggests that the distances inferred from the BAO standard ruler are slightly larger than what a standard cosmological model calibrated to the CMB would predict. When combined with other cosmological data, the DESI results showed that dark energy might be weakening with time, if ever so slightly. It's not an ironclad result, but it is suggestive. We don't know what dark energy is, and cosmologists currently assume that it's constant. But compelling evidence that it does change would help theorists in their pursuit of an explanation for the mysterious acceleration.

Growing tensions

The DESI results come on the heels of another troubling measurement in cosmology: Over the last decade, observations have begun to disagree about the present-day expansion rate of the universe, a value known as the Hubble constant. This



As the universe thins and cools, electrons combine with nuclei to form neutral atoms, allowing light to travel freely.

The photon-baryon coupling ends; the sound waves stall, leaving their imprint on the structure of matter.

The denser shells become seeds where clusters of galaxies begin to grow.

Clusters of galaxies move farther away from each other as the universe expands under the increasing influence of dark energy.

The imprint of BAOs stretches with the expanding universe, preserving a standard ruler scale that we can still measure today.

disagreement is known as the Hubble tension. Estimates taken from distant supernovae point to a higher value than measurements taken from the early universe, especially of the cosmic microwave background. And after years of attempts to rectify this tension, the evidence for it has only grown stronger.

The cosmic web may hold the answer. But to find that answer, cosmologists have to turn to massive computer simulations.

Imagine I gave you a cupcake, and your task was to re-create the recipe. You have to figure out the ingredients that went into the batter, and the precise cooking steps that went into making it. To make it more challenging, you only get one cupcake, and worst of all, you only get to taste little bits of it here and there.

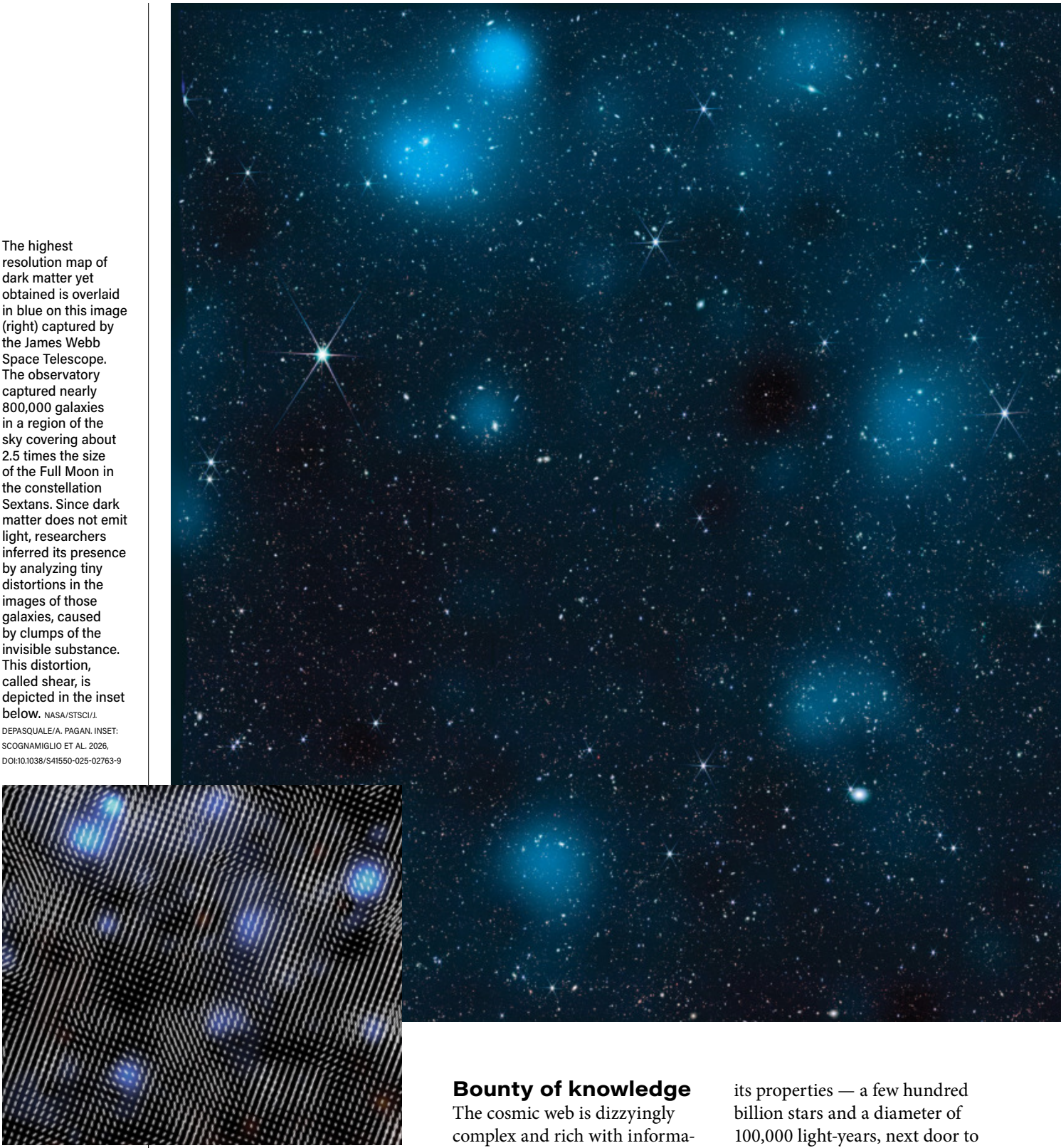
The universe is our cupcake. There's only one cosmos, and we only get slim samples of the cosmic web. But we know what the universe is made of: dark matter, dark energy, and a sprinkling of normal matter. And we know that physical laws — both known and unknown — govern the evolution of the universe.

We can't physically rebake the universe, but we can simulate it. We can take its ingredients, subject them to physical laws, and follow their evolution using computer simulations that solve the complex, interconnected equations that tie everything together.

This is how we know, for example, that the cosmic web is largely made of dark matter. In simulated universes containing only regular matter, there's not enough gravitational attraction to build large structures, not even galaxies, in the 13.8 billion years of cosmic history. It's only by adding dark matter — and its invisible gravitational influence — that we're able to get a cosmic web that matches the statistical properties of observed galaxies in surveys.

This is where the simulations become indispensable. While we can see the galaxies, we are effectively blind to the dark-matter scaffolding that dictates the web's growth. By running massive digital recreations of the cosmos, we can see if a specific flavor of dark matter or a certain strength of dark energy results in the same

THE COSMIC WEB MAY HOLD THE ANSWER. BUT TO FIND THAT ANSWER, COSMOLOGISTS HAVE TO TURN TO MASSIVE COMPUTER SIMULATIONS.



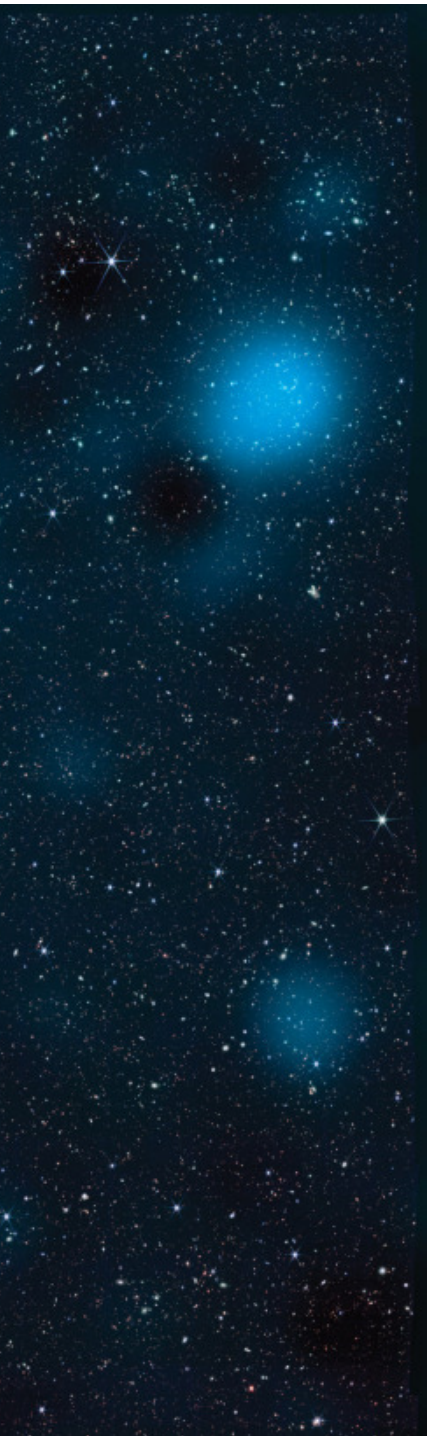
The highest resolution map of dark matter yet obtained is overlaid in blue on this image (right) captured by the James Webb Space Telescope. The observatory captured nearly 800,000 galaxies in a region of the sky covering about 2.5 times the size of the Full Moon in the constellation Sextans. Since dark matter does not emit light, researchers inferred its presence by analyzing tiny distortions in the images of those galaxies, caused by clumps of the invisible substance. This distortion, called shear, is depicted in the inset below. NASA/STSCI/J. DEPASQUALE/A. PAGAN. INSET: SCOGNAMIGLIO ET AL. 2026, DOI:10.1038/S41550-025-02763-9

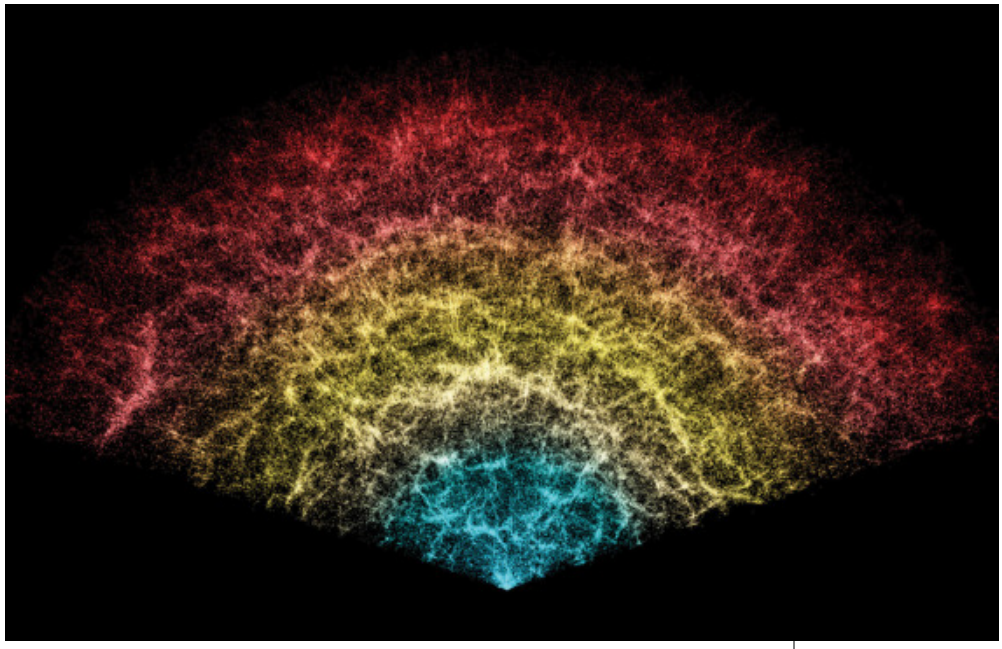
kind of skeleton we observe, with structures like Laniakea. Any proposed solution to the Hubble tension must pass this test: If a recipe doesn't bake the right cupcake, it gets tossed in the trash.

Bounty of knowledge

The cosmic web is dizzyingly complex and rich with information. But the galaxies in the web aren't shaped by dark matter and dark energy alone. Star formation, black holes, the mergers and cannibalization of smaller galaxies — all of these processes leave their mark on the cosmic web, too.

Our Milky Way Galaxy owes its properties — a few hundred billion stars and a diameter of 100,000 light-years, next door to Andromeda within the Local Group, racing toward the Virgo Cluster — to a combination of all of these factors. For cosmologists, separating the dark matter and dark energy signal from the other polluting factors is a difficult task, even after a century of research.





The structure of the cosmic web is visible in this slice of a 3D map of galaxies compiled by the Dark Energy Spectroscopic Instrument (DESI) on the Nicholas U. Mayall 4-meter Telescope at Kitt Peak National Observatory. The ripples are the imprint of baryon acoustic oscillations; note their characteristic size of roughly 500 million light-years.
DESI COLLABORATION/NOIRLAB/NSF/AURA/R. PROCTOR

And so researchers have traditionally turned to simple summary statistics to guide them, like the average distance between galaxies. Despite their simplicity, these techniques have proved remarkably powerful, uncovering crucial cosmological clues like the BAO signal and validating the existence of dark energy.

Modern and upcoming surveys hope to squeeze even more information out of the cosmic web. In addition to current ground-based campaigns like DESI, both NASA and ESA have developed space-based cosmological observatories.

The European-led effort is Euclid, a space telescope that launched in 2023 to the Earth-Sun L2 point, around 1 million miles (1.5 million kilometers) from Earth. The U.S. effort, NASA's Nancy Grace Roman Telescope, is nearly complete and on track to launch this fall.

Complementing these is the Vera C. Rubin Observatory, built by the U.S. National Science Foundation and the Department of Energy, which is conducting a 10-year survey that will provide a massive dataset of hundreds of millions of galaxies.

These surveys will employ traditional techniques and summary statistics. But they will also use new tools in their dissection of the cosmic web. For example, new surveys are exploiting an effect called cosmic shear. As light from distant galaxies filters through the cosmic web, the light gets bent here and there by the influence of gravity as it passes by dense filaments. This distorts — or shears — the images of galaxies ever so slightly, and by studying that distortion cosmologists can map out in detail where the dark matter is hiding.

Another new technique leverages cosmic voids. Long forgotten as the empty deserts in the cosmic web, the voids are actually rich with information. Their sizes, shapes, and distributions reflect the influence of dark energy in the past 5 billion years. Indeed, because they are empty of matter, they are filled with dark energy — they are the locations where accelerated expansion is actively tearing apart the universe, and in time the voids will continue to expand and dissolve everything around them.

Our forays into the wider universe are just beginning, and we are just now starting to unveil the cosmic web for what it is. The largest pattern found in nature, the cosmic web is beautiful, intricate, effervescent … and the key to understanding everything.

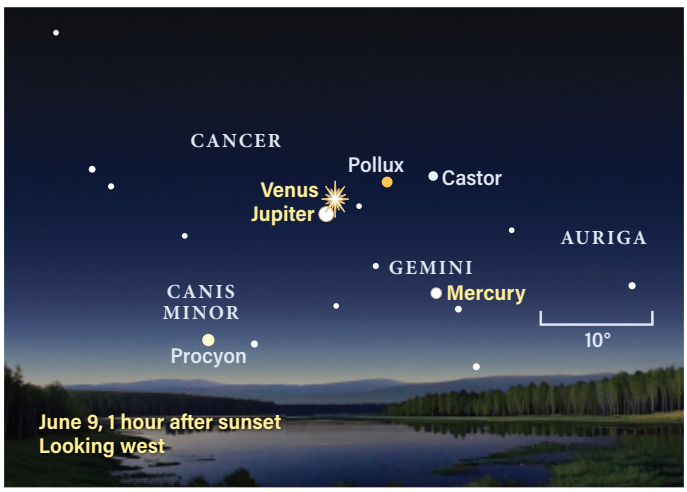
Paul Sutter *is a cosmologist, science communicator, NASA external advisor, and U.S. cultural ambassador. He is an associate research scientist at Johns Hopkins University.*

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.
BY MARTIN RATCLIFFE AND ALISTER LING

Venus (top, upper right) and Jupiter (to Venus' lower left) appeared 3° apart in the March 2012 sky. This month, the two worlds return to the same close alignment, but this time less than 2° apart. ALAN DYER

Coming together



Venus and Jupiter come closest the evening of June 9, meeting in Gemini. Mercury is also visible, closer to the horizon. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

JUNE 2026
Venus and Jupiter meet

Mercury reaches greatest elongation in the evening sky this month. Venus and Jupiter have a spectacular conjunction, and later in the month the Moon occults Venus. Meanwhile, Jupiter drops deeper into twilight as it sinks toward next month's conjunction with the Sun. The morning sky hosts ever-more-prominent Saturn, while Mars and Uranus meet in Taurus.

Soon after sunset, look west for **Mercury**, at its best evening apparition for the year. On June 1, it's an easy object 10° high 30 minutes after sunset. If you're in doubt about finding Mercury, first find bright Jupiter and Venus — which, like Mercury, lie along the ecliptic. Extend a line through the brighter planets (higher in the west) down toward the horizon and you'll find Mercury, shining at magnitude –0.5.

Mercury dims to magnitude 0 by the 8th, but climbs to 12° high 30 minutes after sunset. It's hard not to pay attention to Jupiter and Venus 14° above Mercury — on the 8th and 9th, these planets are at their closest. We'll visit them shortly.

Mercury continues to slowly fade but climb higher, reaching greatest elongation on the 15th, when it stands 25° east of the Sun. At magnitude 0.5, it remains an easy object. Lucky observers may also see a young crescent Moon standing 5° high 30 minutes after sunset.

On the 16th, the Moon is more obvious, roughly 4° from both Mercury and Jupiter, forming a nice triangle. Venus stands 7° above Jupiter. It's a photogenic grouping in the deepening twilight.

By June 20, Mercury is magnitude 0.8 and stands 4.5° west of Jupiter. The bright star Pollux in Gemini now forms the point of an elongated triangle with the two planets. On the 25th, Mercury has faded another 0.5 magnitude and is more difficult to spot as it drops closer to the horizon, with Jupiter following more slowly. Look for Mercury 4° high 45 minutes after sunset, with Jupiter less than 4° away.

June opens with **Jupiter** and **Venus** roughly 7.5° apart. Venus is brighter at magnitude –4.0; Jupiter comes in at magnitude –1.9 and shaves 0.1 magnitude off by midmonth. Watch each night as Venus climbs higher to meet Jupiter. Both planets are visible within 30 minutes of sunset and stand more than 20° high in the western sky. In the first week of June, both planets set by 11:30 P.M. local daylight time, so there's plenty of time to observe them.

Venus and Jupiter reach a stunning conjunction in early June. For two nights, June 8

OBSERVING HIGHLIGHT

VENUS and **JUPITER** stand less than 2° apart in the evening sky on June 8 and 9.

and 9, they're at their closest. On June 8, the gap spans 1.7°, and the next night they're 1.6° apart. The pair is joined by the brightest stars in Gemini, Castor and Pollux, just a few degrees away.

Both planets are visible in low-power telescopes (1.7° or greater field of view) on the nights they're closest. On the 9th, Venus reveals a 77-percent-lit disk spanning 14".

Jupiter, meanwhile, is 33" wide even though it is far more remote. Three of the four Galilean moons are visible, with Ganymede hidden behind the planet. Callisto and Europa lie to the west, with both moons' shadows on the jovian cloud tops this evening.

After the conjunction, Venus continues east relative to the background stars. On the 17th, the crescent Moon occults Venus in daylight. The event is visible across the contiguous U.S., and timing depends on your location. Venus disappears from Baltimore's sky at 3:49 P.M. EDT; from Austin, Texas, at 2:24 P.M. CDT; and from Denver at 12:55 P.M. MDT. You can find disappearance and reappearance times at www.lunar-occultations.com/iota/bstar/0617venus.htm for many cities. Venus' reappearance at the bright limb of the Moon is hard to catch but will be well worth viewing because Venus appears as a brilliant

— *Continued on page 36*

RISING MOON | Craters, cracks, and domes

TODAY'S SEA OF TRANQUILLITY was once untranquil. It began 4 billion years ago with a giant impact excavating a large basin. Millions of years later, lava erupted through the breaks in the floor, from cracks along stress lines created by other large impacts. During a second round of upwelling lava, the terrain heaved unevenly from below, causing a scarp or fracture, while in other places lava tubes collapsed into rilles. Nearby, some volcanoes made it to the surface, but the failed ones created domes. Space rocks slamming in millennia later added the final touch.

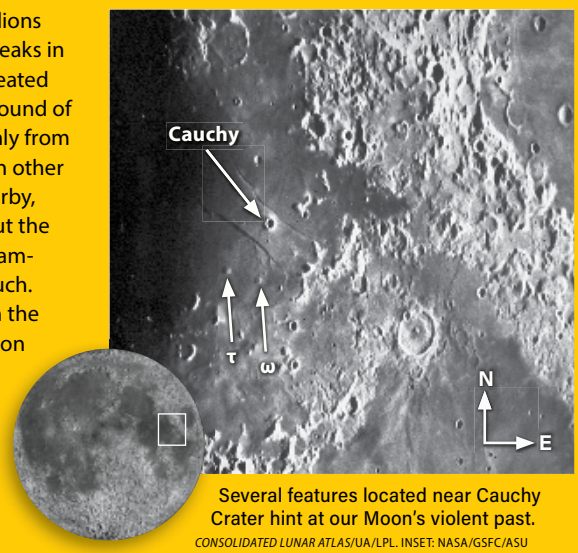
Roughly five days after New Moon, on the 19th, the Sun rises on the fascinating region of crater Cauchy, just north of the terminator's midpoint. The terminator is the line dividing night from day, but at such a young age, the dark face of our sister Luna might be modestly lit by gray earthshine, sunlight reflected from Earth's dayside.

The crater itself is a small, 7-mile-wide simple impact feature with nice sharp edges — evidence of relative youth. Immediately to Cauchy's north is a prominent rille. Years of tiny impacts have softened its edges. Within a couple of Earth days, the higher Sun angle shines directly into the rille, wiping out the shadows and making it all but invisible.

South of Cauchy, a prominent fault scarp lies parallel to the rille. Well known to lunar hounds, the fault is second only to the famous Straight Wall. At sunrise the scarp casts a nice, sharp shadow westward, but the dark line also disappears a couple of Earth evenings later.

A real bonus in this region at the edge of Mare Tranquillitatis is a pair of lava domes. Look for the small light-dark pairing caused by these hills protruding into the sunlight. The eastern dome, cataloged as omega (ω), is likely a shield volcano, while the western one, tau (τ), appears to have been formed by uplifting from below.

Cauchy



Several features located near Cauchy Crater hint at our Moon's violent past.
CONSOLIDATED LUNAR ATLAS/UA/LPL. INSET: NASA/GSFC/ASU

METEOR WATCH | Light up the night

Light and dark

This June 2025 shot shows regular clouds (dark, in the foreground at top) and noctilucent clouds (bright white and blue, in the background at bottom) together in the sky above southern Alberta. ALAN DYER

THERE AREN'T any major meteor showers this month. However, another phenomenon in Earth's atmosphere is of interest. The summer season is a great time to look for noctilucent (night-glowing) clouds. These occur when ice crystals form on high-flying dust particles and are typically visible from latitudes between 55° and 70° north. Their pearly-white appearance remains sunlit long after any lingering regular clouds show up dark against the deepening twilight. This is because noctilucent clouds are much higher than regular clouds — more than 50 miles up, some 10 times the height of cirrus clouds.

At the same time, be on the lookout for the occasional fireball, which can happen at any time of night.

STAR DOME

HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

midnight June 1
11 P.M. June 15
10 P.M. June 30

Planets are shown at midmonth

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

STAR MAGNITUDES

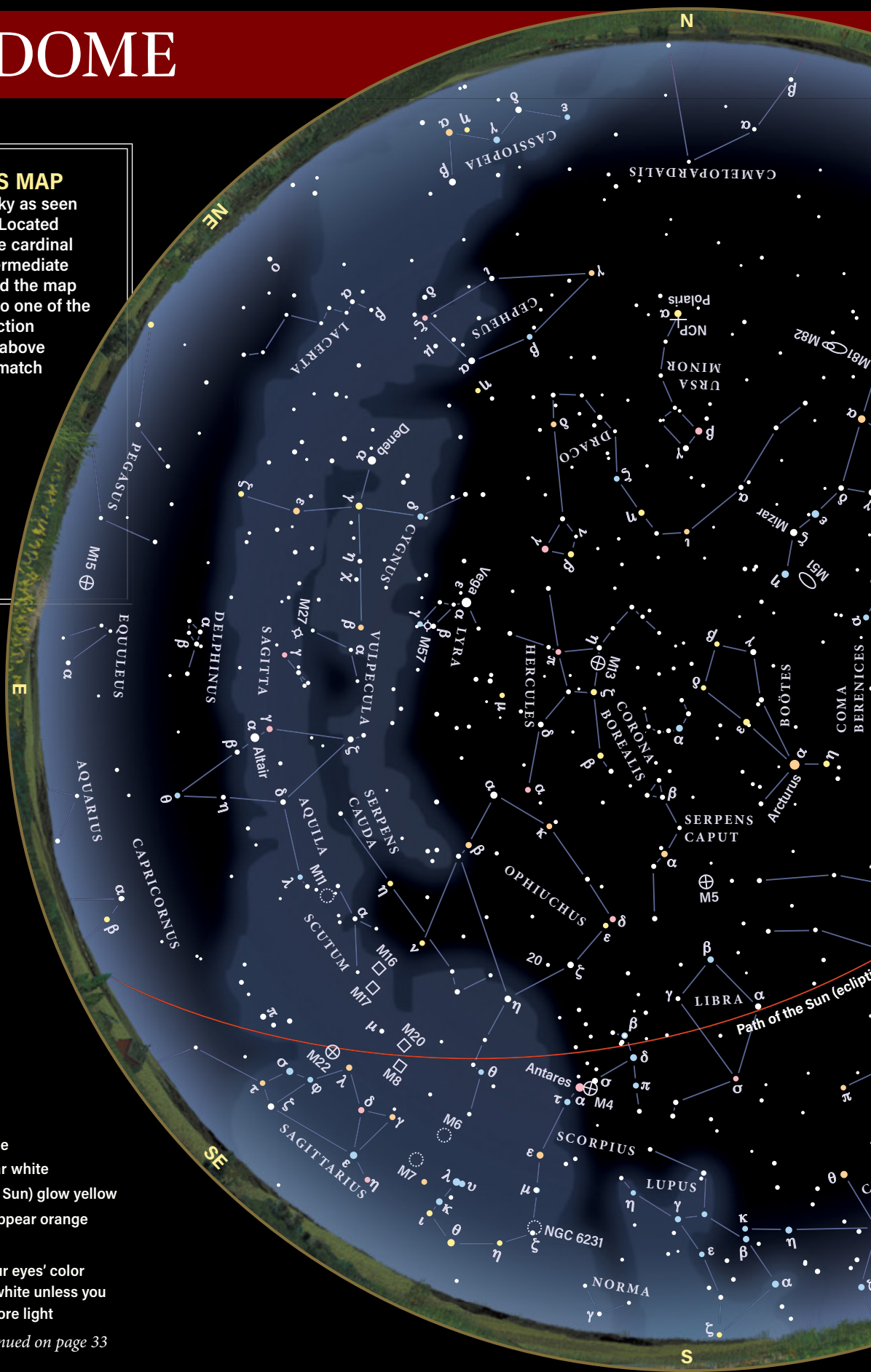
- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

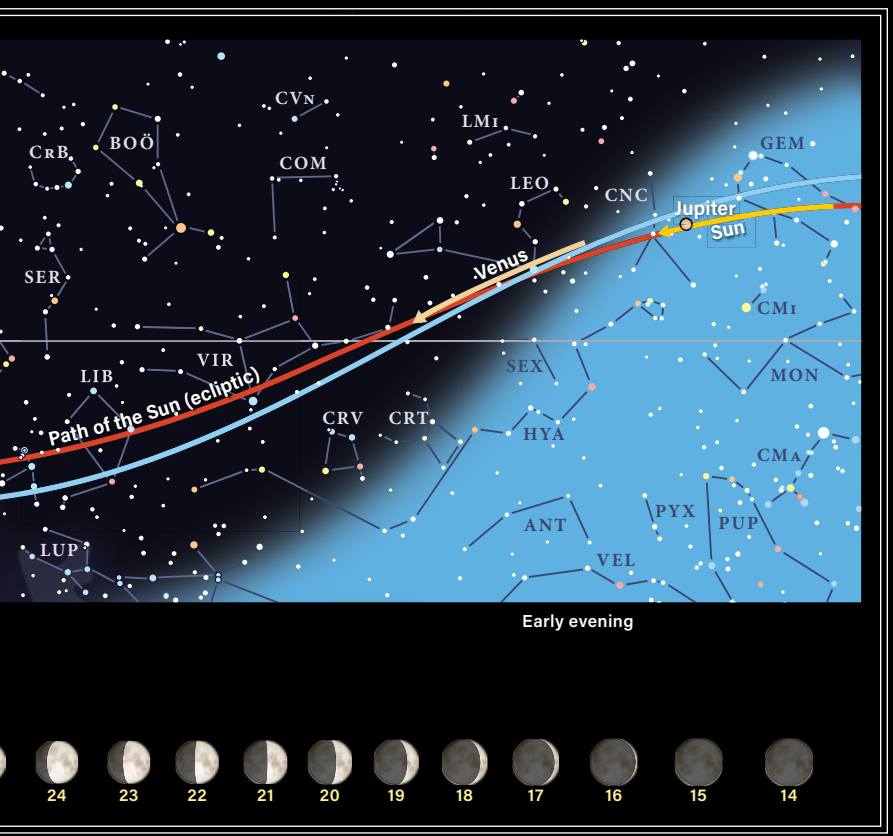
— Continued on page 33



This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

*** Lift out the center sheet (pages 29–32) to view July's Paths of the Planets in full.**

JULY 2026



Early evening

Callisto

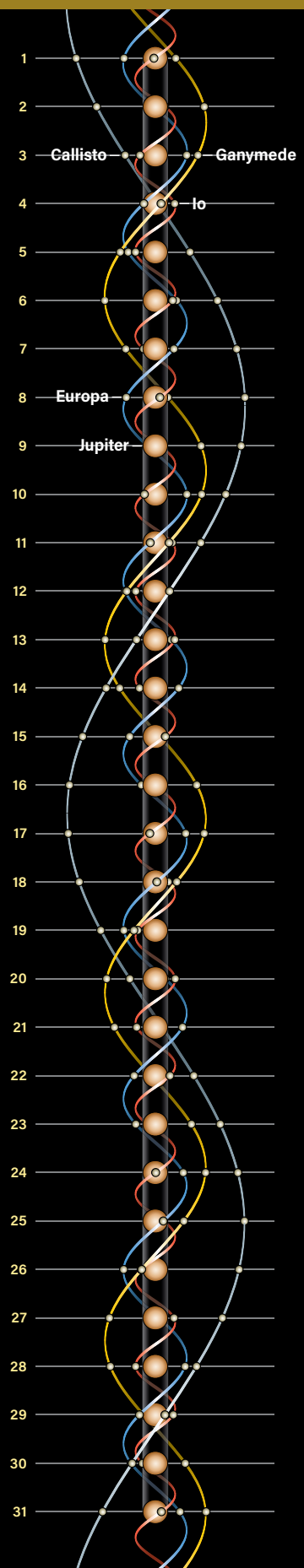
Europa

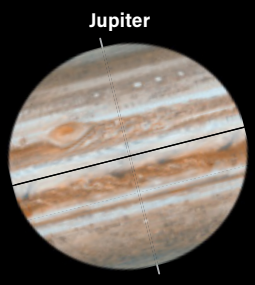
Io

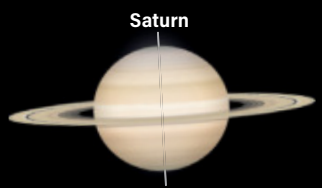
Ganymede

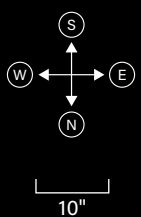
JUPITER'S MOONS

Dots display positions of Galilean satellites at 11 P.M. EDT on the date shown. South is at the top to match the view through a telescope.









Uranus Neptune Pluto

MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
July 15	July 15	July 1	July 15	July 15	July 15	July 15
1.3	9.0	–1.8	0.7	5.8	7.7	15.0
4.5"	0.4"	31.7"	17.9"	3.5"	2.3"	0.1"
94%	99%	100%	100%	100%	100%	100%
2.062	3.525	6.213	9.265	20.118	29.548	34.564
1.459	2.736	5.276	9.459	19.455	29.880	35.556
4h38.0m	5h11.4m	8h08.3m	0h56.3m	4h08.1m	0h17.0m	20h30.5m
21°58'	21°02'	20°37'	3°22'	20°47'	0°20'	–23°20'

STAR DOME

HOW TO USE THIS MAP

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10 P.M. July 31

Planets are shown at midmonth

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- Planetary nebula
- Galaxy

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- 5.0

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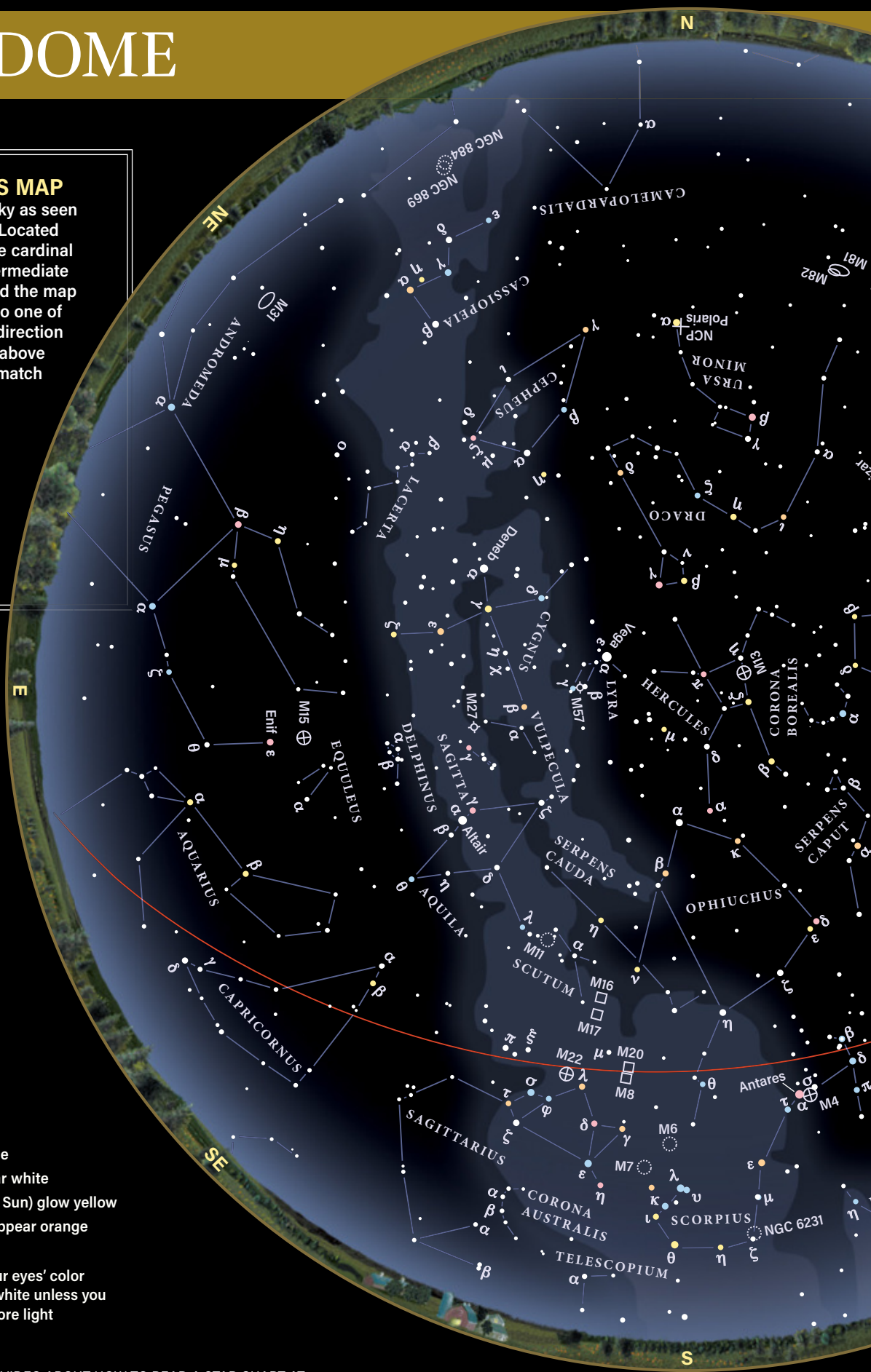
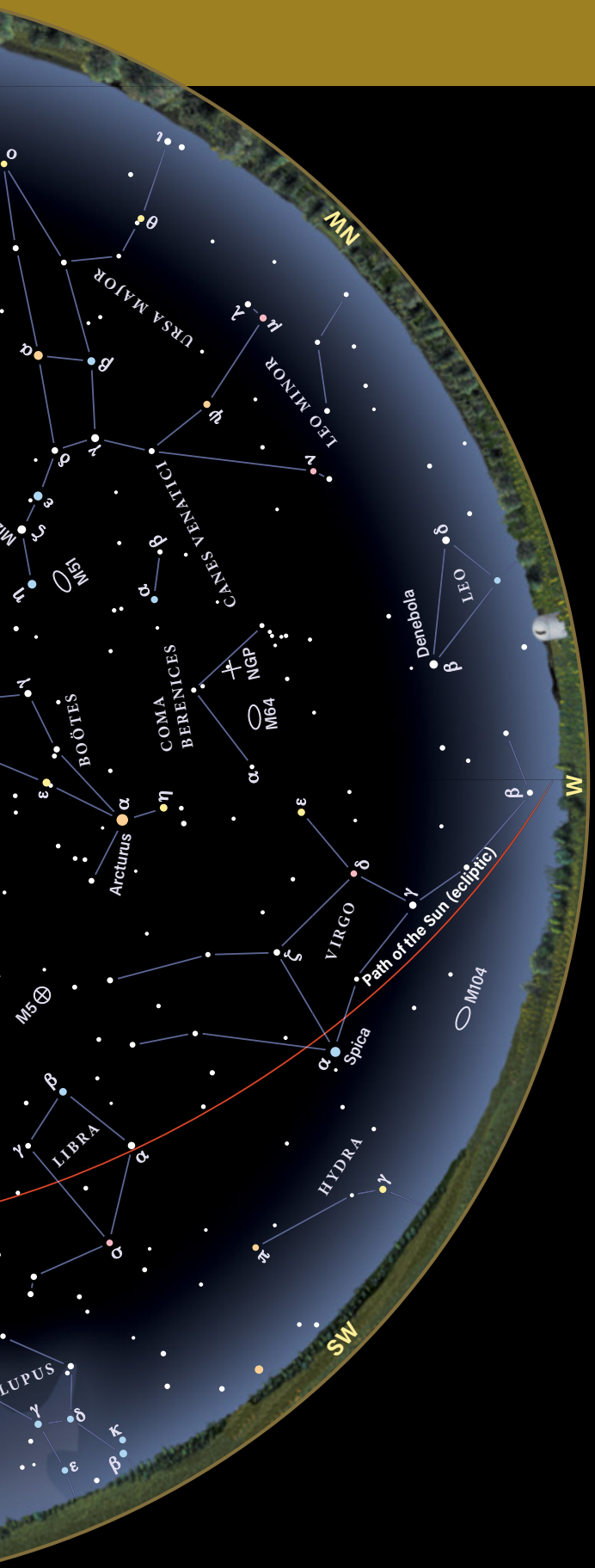


BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**



JULY 2026

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

4 Mars passes 0.1° south of Uranus, 1 A.M. EDT
Mercury passes 10° south of Pollux, 7 A.M. EDT

6 Earth is at aphelion (94.5 million miles from the Sun), 1 P.M. EDT
The Moon passes 5° north of Neptune, 11 P.M. EDT

7 Last Quarter Moon occurs at 3:29 P.M. EDT
The Moon passes 7° north of Saturn, 6 P.M. EDT
Neptune is stationary, midnight EDT

8 Asteroid Melpomene is at opposition, 4 P.M. EDT

9 Venus passes 1.1° north of Regulus, 10 A.M. EDT
Asteroid Flora is at opposition, 6 P.M. EDT

11 The Moon passes 5° north of Uranus, 3 A.M. EDT
The Moon passes 5° north of Mars, 11 A.M. EDT

12 Mercury is in inferior conjunction, 9 P.M. EDT

13 The Moon is at perigee (223,142 miles from Earth), 3:57 A.M. EDT

14 Mars passes 5° north of Aldebaran, 3 A.M. EDT
New Moon occurs at 5:44 A.M. EDT
The Moon passes 2° north of Jupiter, 11 P.M. EDT

16 The Moon passes 0.5° south of Regulus, 9 P.M. EDT

17 The Moon passes 2° south of Venus, 1 P.M. EDT

21 First Quarter Moon occurs at 7:06 A.M. EDT

23 Mercury is stationary, 1 P.M. EDT

24 The Moon passes 0.6° south of Antares, 6 P.M. EDT

25 The Moon is at apogee (251,996 miles from Earth), 12:45 P.M. EDT

26 Asteroid Juno is at opposition, 1 P.M. EDT

27 Pluto is at opposition, 3 A.M. EDT
Saturn is stationary, 7 P.M. EDT

28 Asteroid Bamberga is at opposition, 5 A.M. EDT

29 Jupiter is in conjunction with the Sun, 8 A.M. EDT
Full Moon occurs at 10:36 A.M. EDT

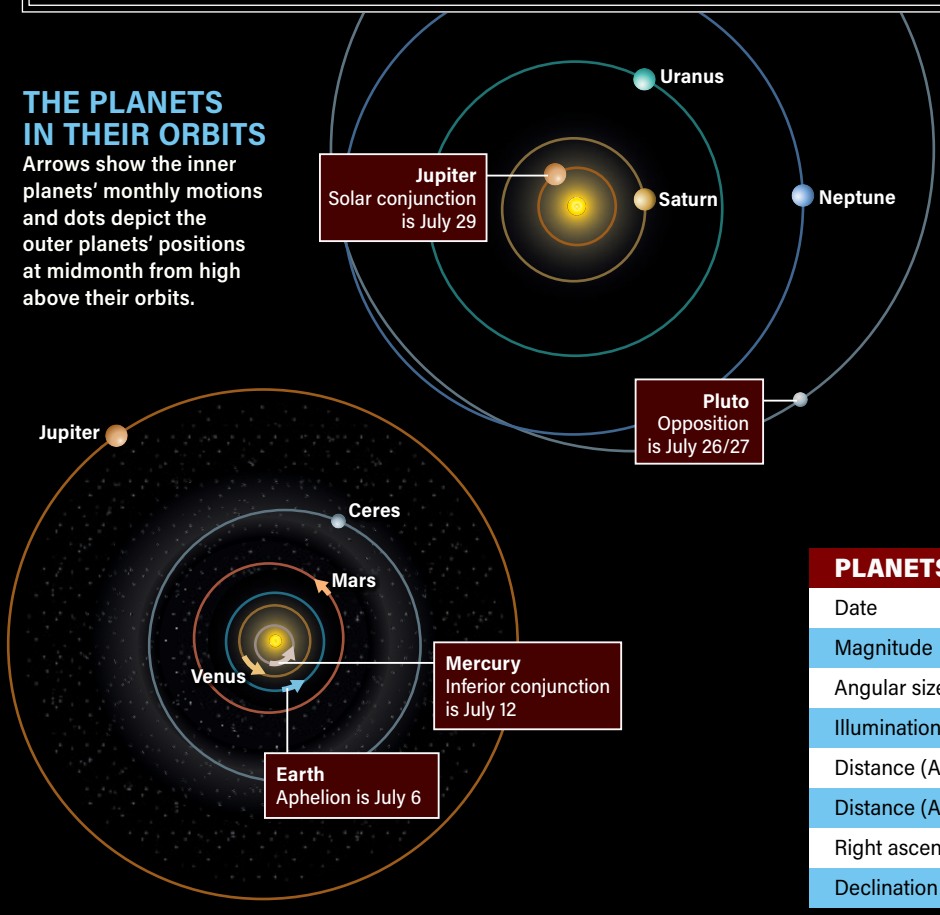
30 Southern Delta Aquariid meteor shower peaks

PATHS OF THE PLANETS

To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

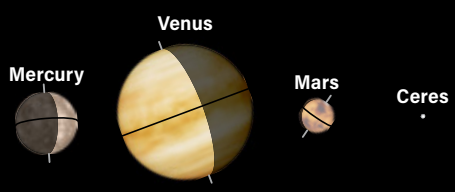
THE PLANETS IN THEIR ORBITS

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.



THE PLANETS IN THE SKY

These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



PLANETS	MERCURY	VENUS
Date	July 31	July 15
Magnitude	0.5	–4.2
Angular size	8.2"	17.8"
Illumination	31%	64%
Distance (AU) from Earth	0.825	0.935
Distance (AU) from Sun	0.360	0.724
Right ascension (2000.0)	7h18.3m	10h30.9m
Declination (2000.0)	19°47'	10°36'

— *Continued from page 28*

JUNE 2026

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

1 The Moon is at apogee (252,504 miles from Earth), 12:33 A.M. EDT

3 Asteroid Juno is stationary, 3 P.M. EDT

4 Jupiter passes 6° south of Pollux, 7 A.M. EDT

8 Last Quarter Moon occurs at 6:01 A.M. EDT

Venus passes 5° south of Pollux, noon EDT

9 Venus passes 1.6° north of Jupiter, 8 A.M. EDT

The Moon passes 4° north of Neptune, 3 P.M. EDT

10 The Moon passes 6° north of Saturn, 8 A.M. EDT

12 The Moon passes 6° north of Mars, 5 P.M. EDT

13 The Moon passes 5° north of Uranus, 3 P.M. EDT

14 The Moon is at perigee (221,952 miles from Earth), 7:20 P.M. EDT

New Moon occurs at 10:54 P.M. EDT

15 Asteroid Irene is at opposition, 6 A.M. EDT

Mercury is at greatest eastern elongation (25°), 4 P.M. EDT

16 The Moon passes 3° north of Mercury, 4 P.M. EDT

17 The Moon passes 3° north of Jupiter, 3 A.M. EDT

The Moon passes 0.3° north of Venus, 4 P.M. EDT

19 The Moon passes 0.3° south of Regulus, 11 A.M. EDT

21 Summer solstice occurs at 4:25 A.M. EDT

First Quarter Moon occurs at 5:55 P.M. EDT

23 Mercury passes 7° south of Pollux, 3 P.M. EDT

27 The Moon passes 0.4° south of Antares, 11 A.M. EDT

28 The Moon is at apogee (252,441 miles from Earth), 3:11 A.M. EDT

Mercury is stationary, 10 P.M. EDT

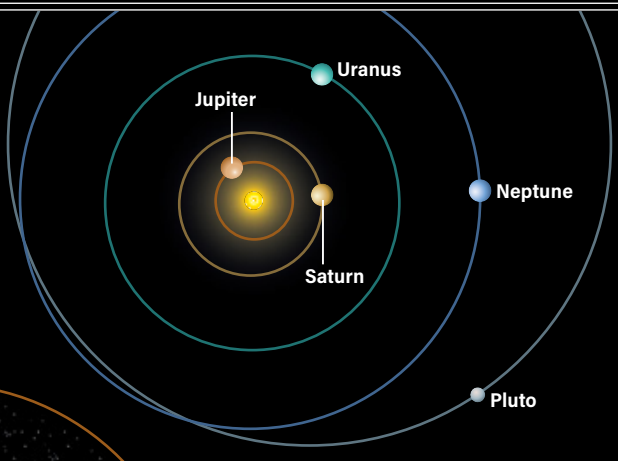
29 Full Moon occurs at 7:57 P.M. EDT

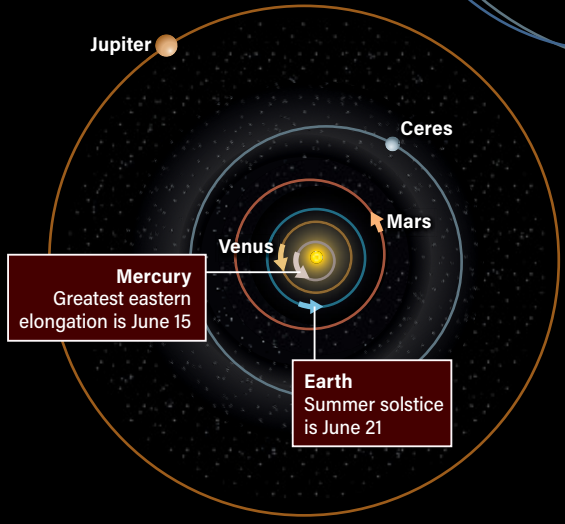
PATHS OF THE PLANETS

To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

THE PLANETS IN THEIR ORBITS

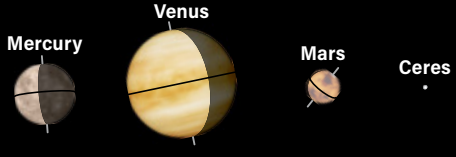
Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.





THE PLANETS IN THE SKY

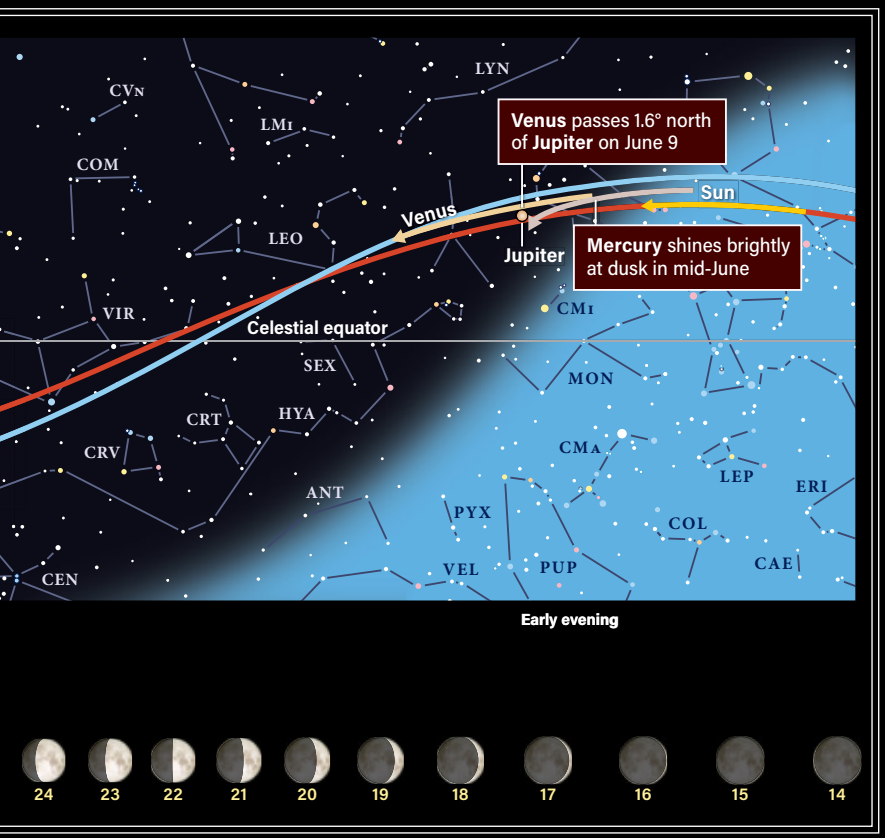
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



PLANETS	MERCURY	VENUS
Date	June 15	June 15
Magnitude	0.5	–4.0
Angular size	8.0"	14.4"
Illumination	40%	75%
Distance (AU) from Earth	0.836	1.161
Distance (AU) from Sun	0.430	0.720
Right ascension (2000.0)	7h18.8m	8h16.6m
Declination (2000.0)	23°21'	21°49'

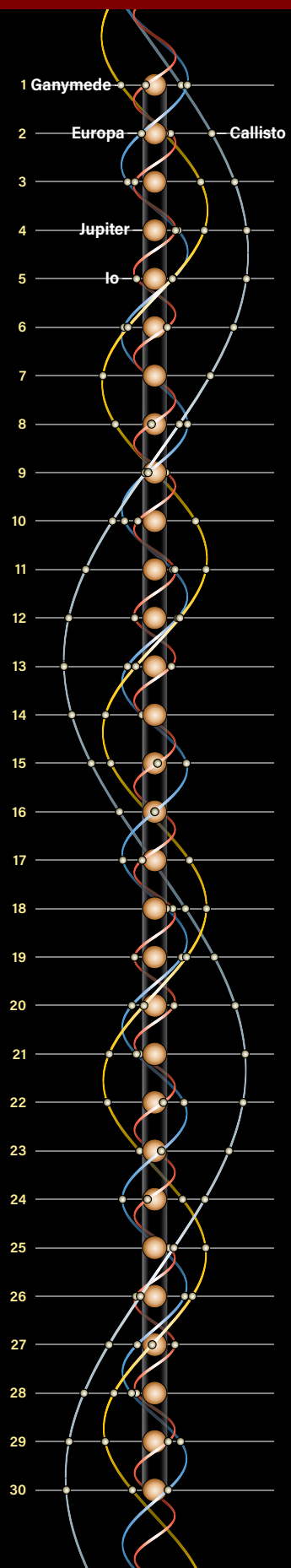
This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

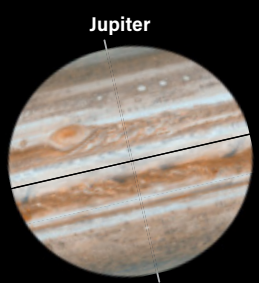
JUNE 2026

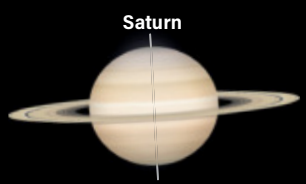


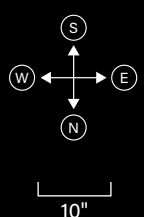
JUPITER'S MOONS

Dots display positions of Galilean satellites at 11 P.M. EDT on the date shown. South is at the top to match the view through a telescope.







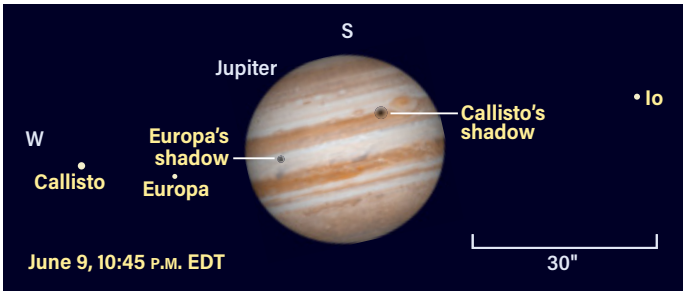


Uranus Neptune Pluto

MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
June 15	June 15	June 15	June 15	June 15	June 15	June 15
1.3	8.9	–1.8	0.8	5.8	7.8	15.1
4.4"	0.4"	32.3"	17.0"	3.5"	2.3"	0.1"
96%	100%	100%	100%	100%	100%	100%
2.151	3.715	6.095	9.756	20.405	30.046	34.767
1.425	2.761	5.271	9.468	19.461	29.881	35.535
3h09.5m	4h20.9m	7h54.2m	0h51.2m	4h01.8m	0h16.5m	20h32.9m
17°11'	18°45'	21°17'	2°59'	20°30'	0°19'	–23°07'

 — Continued from page 27

Two shadows



On June 9, when Jupiter and Venus stand close, some observers can catch both Europa and Callisto's shadows crossing Jupiter together. Ganymede is behind Jupiter in an occultation at this time.

jewel in contrast with the lunar limb.

A few hours later, the Moon crosses the Beehive star cluster (M44). The eastern half of the U.S. gets the better view, seeing some stars disappear at the dark limb. By the time evening falls across the Mountain time zone, stars are reappearing at the bright limb in twilight, a difficult observation. Venus shines 2.3° northwest of the cluster.

On June 18, the gap between M44 and Venus closes to only 1.3° — a stunning binocular sight. On the 19th, Venus stands 45' north of M44.

The line of planets in the western sky on the 20th is a lovely sight, spanning 16° from Venus to Mercury, with Jupiter 11° from Venus. Castor and Pollux, 12° and 8° northwest of Jupiter, respectively, add to the elegant scene. Mercury is first to set at 10 P.M. local daylight time, followed 20 minutes later by Jupiter. Venus sets at 11 P.M.

By the end of June, Venus has moved into Leo and stands 17° high in the west 45 minutes after sunset. Jupiter is only 5° high, quickly lost in twilight.

Returning to Jupiter, there are a few noteworthy events early in the month. On June 7, Io is occulted by the planet's disk at 9:32 P.M. MDT. Europa follows it behind Jupiter's limb at 10:11 P.M. MDT.

On June 9, two shadows are crossing Jupiter's disk from east to west as night falls across the Midwest. Europa's shadow leads, with Callisto's larger shadow following. Callisto and Europa stand west of Jupiter. Europa's shadow ends its transit at 10:13 P.M. CDT, as Jupiter is getting quite low in the Midwest. Callisto's shadow transit ends after Jupiter sets along the Pacific coast.

Io and its shadow transit on June 15. Io's transit begins at 9:49 P.M. CDT and its shadow follows 42 minutes later. The next night, Europa makes a similar transit. Because of its wider orbit, Europa's shadow follows 79 minutes later. Europa's ingress (9:37 P.M. EDT) is visible across the eastern half of the U.S., with the remainder of the event visible as darkness falls across the rest of the country. Note that Ganymede is occulted at 10:04 P.M. PDT, only visible from the West Coast. Callisto undergoes a similar occultation the following evening, June 17, at 9:30 P.M. CDT, as the Sun is setting in the Mountain time zone.

It's a challenge to catch events as Jupiter sinks in the west, but fun to try. Good luck!

WHEN TO VIEW THE PLANETS

EVENING SKY
Mercury (west)
Venus (west)
Jupiter (west)

MORNING SKY
Mars (east)
Saturn (east)
Uranus (east)
Neptune (southeast)

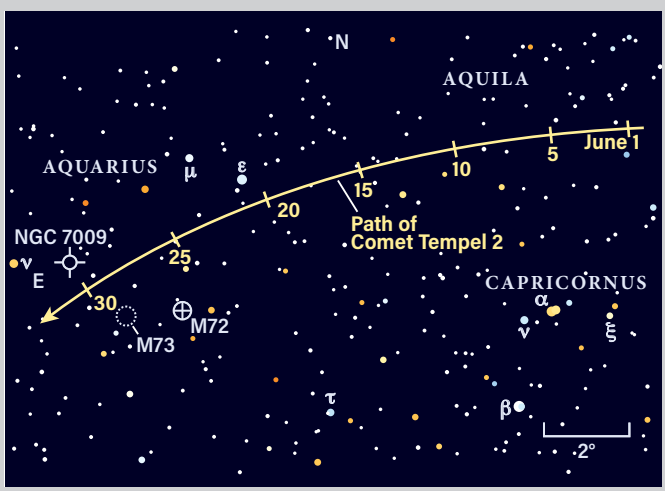
Now we switch to the morning sky, where **Neptune**, rises around 2:30 A.M. local daylight time on June 1, and before 1 A.M. by the 30th. As June opens, magnitude 7.8 Neptune is 3° southwest of 44 Piscium. From 44 Psc, scan with binoculars 2° southwest to find a group of five stars highlighted by a nice 7th-magnitude star. Neptune lies 0.7° from this star, along the same line. As June

COMET SEARCH | Summer companion

CHARLES MESSIER missed this one: Peaking next month, short-period Comet 10P/Tempel is now putting on its best showing since 1967. The solar heat is already enough for both gas and dust production to give us a decent telescopic target brighter than 9th magnitude. Head out of the city during New Moon to see it in small scopes and large binoculars, with the best views toward the end of the short night, following the Milky Way's core.

Also called Tempel 2, this comet can appear like a globular cluster at low power. First take in M2, an easy magnitude 6.5, then slew over to M75 at magnitude 8.5 and M72 at magnitude 9.3. Note the brightness profile of each for comparison to Tempel 2: How quickly does the comet's glow intensify into the middle? Can you notice that the southeast flank is sharply defined as the solar wind pushes back the dust?

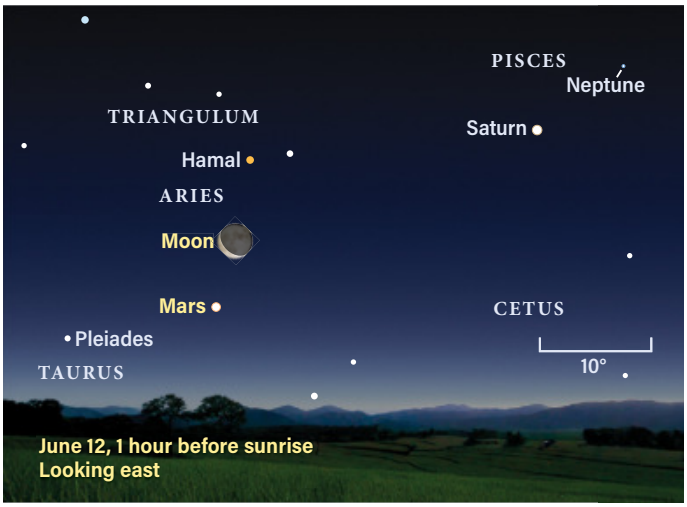
Comet 10P/Tempel



Comet Tempel 2's path takes it invitingly between the Saturn Nebula (NGC 7009) and M72 at the end of the month, although the nearly Full Moon will douse the area with light.

With the inner and outer parts of Tempel 2's orbit not far from Mars and Jupiter, respectively, gravity's relentless tug kept the comet just too far and too faint for the prolific hunter Messier. Discovery had to wait until 1873 provided a good return geometry for Wilhelm Tempel to lay eyes on it.

The Moon and Mars



Use the Moon to help you find Mars before dawn on June 12. Note that Neptune will require optical aid to see; Uranus has just risen above the eastern horizon below the Pleiades, but is not shown here because it is too low to view.

progresses, Neptune moves closer to this grouping. By June 30, Neptune is only 8' west of an 8th-magnitude field star in the grouping. On this date, Neptune stands some 30° high in the southeast at the onset of twilight, offering fine opportunities to spot the bluish-hued planet through your telescope. A waning crescent Moon stands 4.5° northwest of Neptune on June 9.

Saturn rises about half an hour after Neptune and is 10° above the eastern horizon 100 minutes before sunrise on the 1st. By the end of June, Saturn is 27° high in the southeast two hours before sunrise, and getting better each day. It is magnitude 0.7, outshining all the stars in this region.

Telescopes show the tilt of Saturn's rings, reaching 9° by the 30th and revealing their southern side, along with the planet's southern hemisphere. Saturn's disk spans 17" at the equator and 15.5" at the poles. The rings reach 39" across.

Titan, Saturn's brightest moon, crosses due north of Saturn between June 2nd and 3rd. It appears northeast of the planet on the 2nd, and northwest of it on the 3rd. On the following night (the 4th), a field star of the same brightness as Titan lies less than 1' northeast of Titan, so watch for that.

Tethys and Dione undergo a series of transits and shadow transits, only detectable in careful video capture by experienced observers. Dione passes due north of Saturn the mornings of June 19 and 30. Iapetus nears Saturn June 25, standing 1.9' due north of the planet. It's heading to a western elongation in mid-July, when it will be at its brightest. During June, Iapetus shines near 11th magnitude.

Mars rises 90 minutes before the Sun in early June. A great time to spot the Red Planet is June 12, when the waning crescent Moon hangs some 6.5° above magnitude 1.3 Mars in morning twilight. Mars moves from Aries into Taurus by June 20 and stands just under 5° south of the Pleiades star cluster (M45) on June 27. Compare Mars with Aldebaran, which rises about an hour after Mars at the end of June.

Mars' disk is 4" in a telescope, barely revealing surface detail. There's no opposition of Mars this year, but by the end of December its disk will reach 10" in diameter, with opposition in February 2027.

Uranus reached conjunction with the Sun last month and isn't visible in early June. By the 15th, it rises a little over an hour before the Sun. The dim, magnitude 5.8 planet is challenging, but by June 30 it is more than 10° high in the east an hour before sunrise. On that day, Uranus is just 2.5° east of Mars in Taurus.

The summer solstice occurs June 21 at 04:25 A.M. EDT.

Martin Ratcliffe *is a planetarium professional with Evans & Sutherland and enjoys observing from Salt Lake City.* **Alister Ling**, *who lives in Edmonton, Alberta, is a longtime watcher of the skies.*

GET DAILY UPDATES ON YOUR NIGHT SKY AT **www.Astronomy.com/skythisweek.**

LOCATING ASTEROIDS
Two for one everywhere

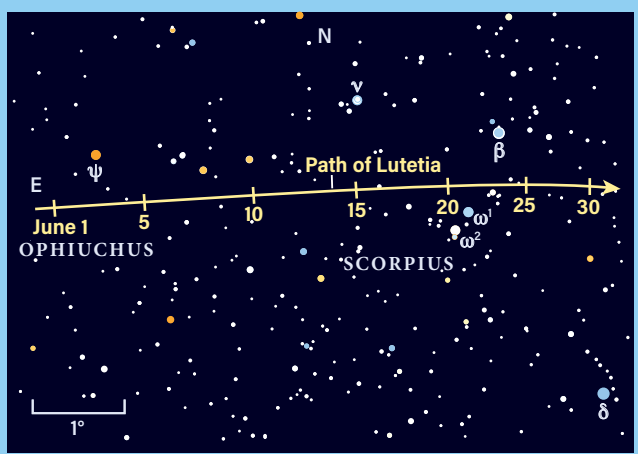
EACH SHIFT OF THE TELESCOPE brings another wonderful sight into view for our earthbound eyes. No matter the light pollution or phase of the Moon, stars shine through the eyepiece — and often enough, an asteroid. 21 Lutetia is a modest 80-mile-wide main-belt world glowing at 10th magnitude this month, which a 6-inch scope can pick up from the suburbs.

On the 4th, Lutetia approaches a 10th-magnitude field star; on the 16th, it's near a 9th-magnitude neighbor. The 23rd and 24th have our rock sliding between even brighter distant suns. There are a lot of background stars as we peer toward the center of our galaxy. To be sure you've positively identified the asteroid, make a quick sketch of the field with at least three dots, then come back another night to confirm which one has moved.

Since you're buzzing Scorpius' brain, look at Omega[1] (ω^1) and Omega[2] (ω^2) Scorpii through binoculars, and follow up in the scope with dazzling Beta[1] (β^1) and Beta[2] (β^2) just to the north. And Nu (ν) Scorpii stood out for Agnes Clerke as the most beautiful quadruple in the heavens. Do you agree?

The Rosetta spacecraft took a close look at Lutetia back in 2010, while on its way to Comet 67P/Churyumov–Gerasimenko.

Seeing double



Lutetia is passing several multiple-star systems in Scorpius this month.

COSMIC CATACLYSM AT THE

JWST studied a supernova near the edge of the universe and found it appears a lot like those that happen nearby. BY RICHARD TALCOTT

A LONG TIME AGO, in a galaxy far, far away, a massive star collapsed, triggering a supernova explosion so bright it could be seen across the universe. When the light reached Earth, telescopes around the world and in space quickly focused on the blast. They confirmed it took place just 730 million years after the Big Bang, less than half the age of the previous record-holder.

This timing places the supernova in the heart of the epoch of reionization, when ultraviolet light from the first generation of massive stars was clearing the hydrogen fog that had permeated space during the so-called Dark Ages. Because astronomers know little about the universe's first billion years, any observation from this era opens a new window into cosmic evolution.

It started with gamma rays

The story of the supernova's discovery began March 14, 2025. That's when the Space-based multiband astronomical Variable Objects Monitor (SVOM) satellite detected a 10-second-long burst of gamma rays, earning it the designation GRB 250314A.

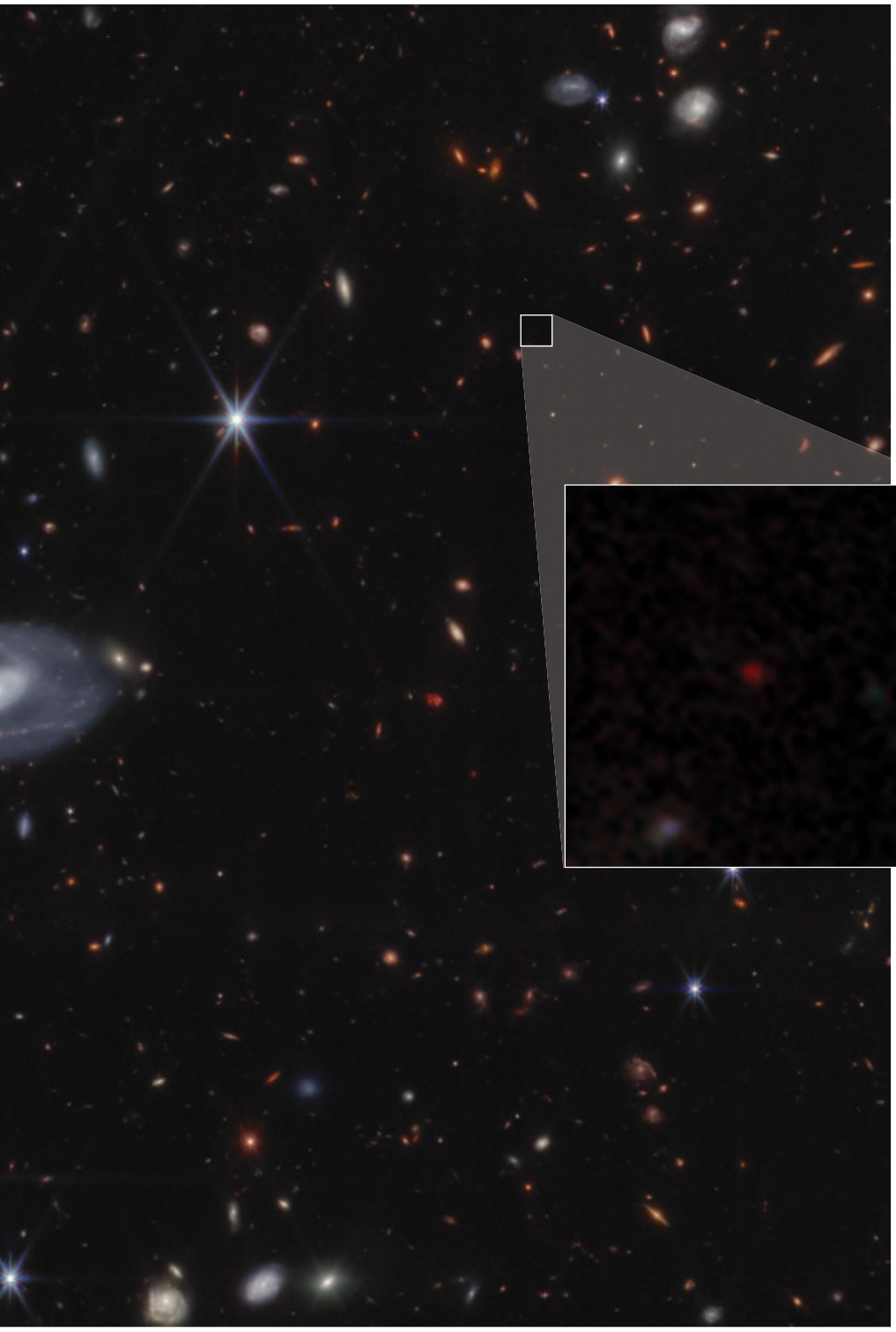
Such long bursts — short gamma-ray bursts last no more than two seconds — typically arise when a star weighing at least 30 solar masses exhausts its nuclear fuel and collapses. This generates a shock wave that tears through the star's outer layers and spawns a supernova. The collapsed core produces jets of particles traveling near the speed of light. When these jets pierce the stellar envelope, they emit beams of gamma rays that spread across the universe.

Scientists working on SVOM, a joint Chinese-French mission, promptly alerted their colleagues around the world. Within 1.5 hours, NASA's Neil Gehrels Swift Observatory detected GRB 250314A's X-ray afterglow and established its precise position. Eleven hours later, the 2.6-meter Nordic Optical Telescope on La Palma in the Canary Islands spotted the burst's infrared afterglow. (Despite the telescope's name, it also observes near-infrared light.)

Four hours after that, astronomers focused one of the 8-meter mirrors of Paranal Observatory's Very Large Telescope in Chile on the spot. It captured a spectrum of the fading infrared afterglow, establishing a redshift of about 7.3 and confirming the light took some 13.1 billion years to reach us.

JWST forges the final link

And then astronomers waited. Supernovae typically reach peak brightness two to three weeks after the explosion. But Albert Einstein showed more than a century ago that events at high redshift occur in slow motion. For an object with a redshift of 7.3, actions happen 8.3 times more slowly. The same effect lengthens the wavelength of emitted light by a factor of 8.3.



JWST turned its eye on a galaxy-filled field in the constellation Virgo. The close-up reveals the site of a distant gamma-ray burst, which the observatory confirmed as a core-collapse supernova that took place within the universe's first billion years. The close-up shows the supernova's faint red glow and a hint of its host galaxy. BOTH IMAGES: NASA, ESA, CSA, STSCI, A. LEVAN (IMAPP)

Astronomers took a 3.5-month break, until July 1, to target GRB 250314A with the infrared-sensitive James Webb Space Telescope (JWST). The observatory captured the blast's faint glow and a hint of its host galaxy, confirming it as the earliest supernova ever observed.

"Only Webb could directly show that this light is from a supernova," said lead researcher Andrew Levan of Radboud University in Nijmegen, Netherlands, and the University of Warwick in the United Kingdom, in a press release. The team reported its results in the December 2025 issue of *Astronomy & Astrophysics Letters*. "This observation also demonstrates that we can use Webb to find individual stars when the universe was only 5 percent of its current age," he added.

Astronomers think stars in the early universe were more massive, lived shorter lives, and possessed fewer heavy elements than stars today. Would those conditions have an effect on the supernovae these behemoths produced?

"We went in with open minds," said co-author Nial Tanvir of the University of Leicester in the U.K. "And lo and behold, Webb showed that this supernova looks exactly like modern supernovae." Now researchers must find and scrutinize other early supernovae to look for subtle differences.

Contributing Editor **Richard Talcott** *wrote about JWST's observations of the star cluster Pismis 24 in the April issue.*

DAWN OF TIME

Seven nights in Kyrgyz

stan

After seeing these nightscapes, you'll want to put this country on your vacation list.

TEXT AND IMAGES BY SOUMYADEEP MUKHERJEE

ON MY WAY TO TASH RABAT from Son-Kul, both in Kyrgyzstan, sitting on the comfortable seats of a mini-bus, I had to pinch myself just to realize that it wasn't a dream. I could see green valleys on one side of the road and the rugged brown Pamir Plateau on the other. As someone who loves to travel (and later as an astroimager), I have been to many places in my home country, India, and a few outside. I have experienced many dream locations. But Kyrgyzstan takes the top position. I spent seven nights in this country only to want to come back and drown in its beauty again.

The region housing the constellation Cygnus rises at Tash Rabat.

MAP: *ASTRONOMY*: ROEN KELLY

A surprising choice

In late 2023, I began searching for a suitable place with enough dark skies and landscapes to spend a week in 2024. With almost eight months to go, I looked within India, and Ladakh was my first choice. Back then, I had no clue about Kyrgyzstan's potential and it was not even in the list of top 10 places in my travel notebook.

However, after seeing the extremely high-priced flight tickets to Ladakh, I started considering alternatives. Then I came across an image of the Milky Way from Kyrgyzstan, posted by a traveler on Flickr, and it decided my fate: I would be traveling to Kyrgyzstan. Upon doing more research on potential places to go in the country, I knew I was making the right decision.

A gold mine for photographers

Kyrgyzstan is even more beautiful than pictures of it indicate. I explored four places for astroimaging: Son-Kul, Tash Rabat, Barskoon Valley, and Issyk-Kul. As a photographer, you will find interesting compositions at every step: Son-Kul with its vast lake surrounded by mountains, the stone caravanserai of Tash Rabat, the Barskoon Valley with its mountain river and gorge, and Issyk-Kul with its huge lake and Mars-like canyon. I never ran out of options.

Tips for travelers

If you are an astroimager, a landscape photographer, or even just a person who loves to travel, you should visit Kyrgyzstan at least once. The following suggestions will help you have a better experience during your trip.

Check accessibility: Many dark-sky places here, including Son-Kul and Tash Rabat, are not accessible all year long because of harsh weather conditions. Even if you reach these places, you won't find any accommodations, as nomadic families set up yurt camps seasonally.

I came across an image of the Milky Way from Kyrgyzstan, posted by a traveler on Flickr, and it decided my fate: I would be traveling to Kyrgyzstan.

TOP: The Milky Way rises above snow-capped mountains at Tash Rabat.
ABOVE: Star trails whirl above the 600-year-old caravanserai Tash Rabat.
LEFT: The Big Dipper, shown here above a yurt, never completely sets from Kyrgyzstan.

If you are an astroimager, a landscape photographer, or even just a person who loves to travel, you should visit Kyrgyzstan at least once.

TOP: The Andromeda Galaxy (M31) rises above the mountains at Tash Rabat through strong airglow.
ABOVE: This Kyrgyz yurt was my home for two nights at Tash Rabat.
RIGHT: The Milky Way region of Aquila forms the backdrop to the bust of Yuri Gagarin.

A BIT OF SPACE HISTORY

Although the tour was slow-paced, it was not without a little adventure. Before reaching the Barskoon Valley, I had studied it on maps and found a statue of Russian cosmonaut Yuri Gagarin, who hiked the area after his historic spaceflight. I instantly decided to photograph the statue with the backdrop of the Milky Way.

Since we reached the spot late in the evening, I did not get a chance to explore in daylight. At night, four of us searched for the statue and finally managed after 40 minutes of walking to find it — right beside our accommodations! However, it was fenced and we could not find a way to enter the premises. We also came across a board with "Military Area" written on it. Banking on our good intentions to merely photograph, we decided to jump the fence with our cameras. After getting our images, a little hurried and worried, we left. *—S.M.*

Book your accommodation early: The best time to visit is June to September, when you will also find favorable weather. Most remote places where you will travel for astrophotography do not have permanent accommodations. The yurt camps are limited in number and also only hold a limited number of guests. To ensure a comfortable stay, start talking to camp owners (mostly done via WhatsApp) at least three to four months before your travel dates.

Choose the locations wisely: Remember, one astrophotography location within the country could be 10 to 12 hours away from another, so unless you are spending a month in Kyrgyzstan, choose your destinations wisely. Do not try to visit all of them; select fewer locations and spend more time exploring those.

Rent a car: Although the country has public transport, it won't take you to those dark-sky places. Once you reach Kyrgyzstan (or ahead of your trip), you'll want to rent a car, either with or without a driver. This will not only give you peace of mind, but also require less travel time than buses or trains — and thus allow more opportunity for photography.

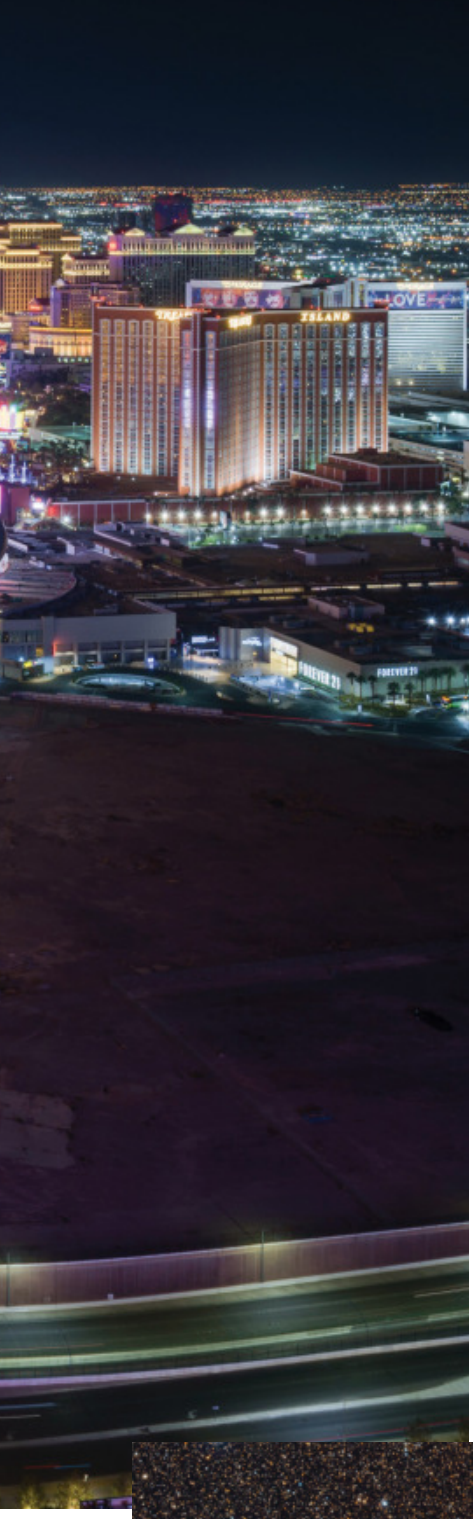
Install a translator app: People in Kyrgyzstan are extremely welcoming and helpful. However, their language is mostly limited to Kyrgyz and Russian. Unless you can speak and understand these languages, install a translator app on your phone. This ensures you will fully understand them and they can understand you.

If you're looking for an astroimaging getaway, Kyrgyzstan should be at the top of your list: This country offers vibrant landscapes and dark skies to travelers. You will have a memorable trip, and the proof will be in the photography you return with.

Soumyadeep Mukherjee *is an amateur astrophotographer, astrophotography educator, and writer from Kolkata, India.*

STARGAZING UNDER CITY LIGHTS

There's still a lot to see beneath light-polluted skies. BY ALAN GOLDSTEIN



MOST AMATEUR ASTRONOMERS live with light pollution. When a free schedule, the New Moon, and the ability to travel to a dark site align, you have a night to remember. But like finding a valuable old coin in your change, such nights are the exception, not the rule.

However, there's no need to consider the rest of your time unworthy. Observing in the city is easier and, believe it or not, more rewarding than you might think.

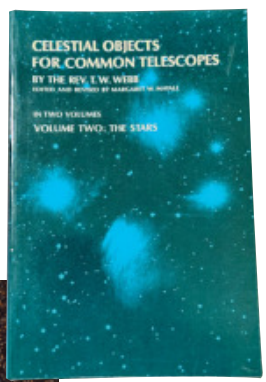
True, the "anti-darkness" filter of an urban environment offers challenges. The ideal observer's solution is to at least get out of town. Head to a park or a location with good horizons (especially south), away from the city's light pollution dome. But sometimes that's not possible: Throughout much of the eastern half of the U.S., towns have small but obvious light domes that may overlap.

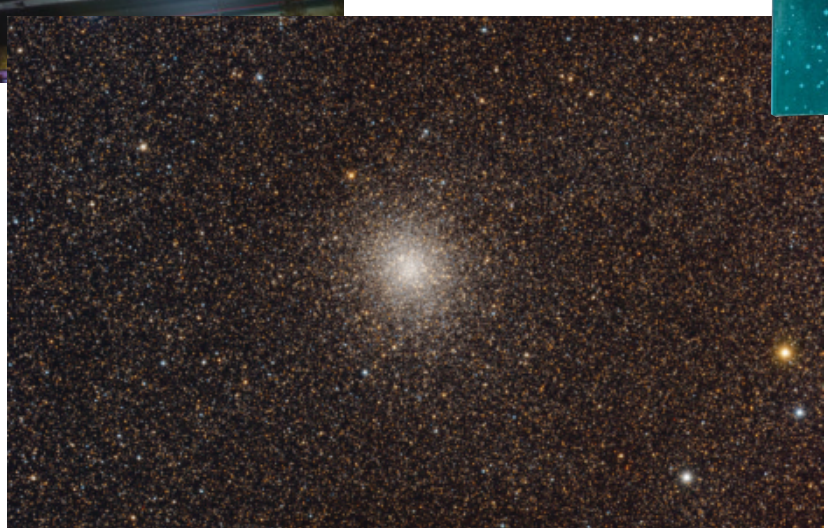
So, rather than waiting to use the telescope in darker pastures, adapt. The rewards and challenges are still there, even if you can't go as deep. After all, you can still see more under such conditions than under a dark sky with clouds!

LEFT: Even from locations near the Las Vegas Strip, determined amateur astronomers can make worthwhile observations. KING OF HEARTS/WIKIMEDIA COMMONS

RIGHT: The author's early choice of observing guides can still be found inexpensively in used bookstores and online. Look for the 1962 edition. RAYMOND SHUBINSKI

BELOW: Globular cluster M22 in Sagittarius is the third-brightest globular in the sky. As such, it's a good target for city-dwelling observers. BERNHARD HUBL





Personal history

I have observed under skies with varying degrees of light pollution for decades, and my sketchbook has numerous pages proving that light pollution shouldn't keep you from pulling out your telescope.

My introduction to observing under light pollution started with attempts to see Comet Kohoutek (C/1973 E1) in late 1973, touted as the comet of the century. That object turned out to be a disappointment.

My first great comet wouldn't be until Comet West (C/1975 V1) became visible to amateur astronomers in March 1975. But in the span between these two icy visitors, I became familiar with the Moon and planets in my backyard "observatory": open air with blanket-covered ladders to block the neighbors' back porch lights. I was lucky to have a family farm with a dark sky for weekends and summers, but I observed on school nights much more frequently.

Eventually I moved beyond the solar system and fell in love with the deep sky. Years of observing from those urban skies gave me an understanding of what success under those conditions looks like. Over time, I developed six rules that I offer here.

Rule No. 1: Know what's up

Before you can figure out which objects you might be able to observe, you need to know what's up. As a new observer, my bible was a reprint of Rev. Thomas William Webb's 1859 classic, *Celestial Objects for Common Telescopes, Volume 2, The Stars*. In it, I read descriptions of double stars, vivid red stars, open and globular star clusters, nebulae, and distant galaxies, and I wanted to find them all. Many other books and magazines (including this one) can help you figure out what's visible from your location, as well as online resources like Stellarium (https://stellarium.org), The Sky Live (https://theskylive.com), and In-The-Sky.org (https://in-the-sky.org).

Rule No. 2: Go for brighter deep-sky objects

Ideal deep-sky objects for urban observing include planetary nebulae and globular

clusters. Both tend to be compact and bear magnification well.

Charles Messier's catalog of deep-sky objects is by far the best list of targets for urban observers. He developed his catalog by finding fuzzy objects easily mistaken as comets. At that time, lists of deep-sky objects were virtually nonexistent, so he noted sky objects that might be misconstrued as a comet using telescopes. Messier hunted comets from downtown Paris in the late 18th century, and while his urban skies were better than most urban areas today, his list remains a great resource for those seeking brighter deep-sky targets.

There are other lists of bright deep-sky objects as well, such as Sir Patrick Moore's Caldwell Catalog. Essentially, if you expand Rule No. 1 to learning some basic characteristics (brightness, size, location) about your target objects before you begin, that will help a lot.

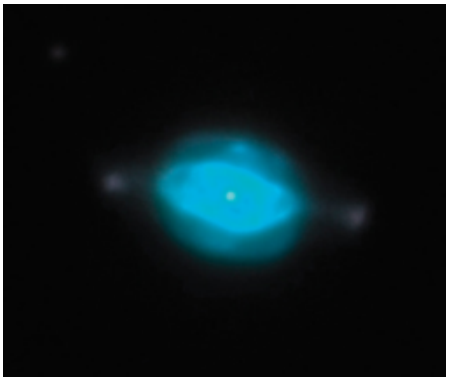
Rule No. 3: Know the best telescopes to use

A telescope with a long focal length at f/8 or higher will provide a darker field of view than a fast telescope with a focal length at f/6 or lower. As a teen, I used a 4-inch f/16 refractor and an 8-inch f/10 Schmidt-Cassegrain in my suburban backyard. This was long before the go-to systems commonly used today, and I discovered that star-hopping with a finder scope is challenging under urban skies. So, if you want to spend time observing rather than hunting for objects, opt for a telescope with a computerized go-to system.

Rule No. 4: Start with stars

When observing in a city, the stars are a good place to start. You can see hundreds of double and multiple stars despite light pollution. Resolving a double star just depends on the aperture, magnification, and the seeing (atmospheric steadiness). Summer skies usually have worse clarity than winter because of higher humidity, but a pool of moist, stagnant air can often translate into steady seeing. A 3-inch scope can resolve many double stars. Move up to a 6-inch, and you'll add fainter and closer pairs.

Double and multiple star showpieces include Albireo (Beta [β] Cygni), the Double Double (Epsilon [ε] Lyrae), and Mizar (Zeta [ζ] Ursae Majoris). These are great for whetting your appetite, not to mention showing family and friends.



FAR LEFT: Planetary nebulae like the Saturn Nebula (NGC 7009) are the best nonstellar targets under light-polluted skies. GARY IMM

LEFT: Albireo (Beta Cygni) is one of the most beautiful double stars in the sky. To most observers, its stars register as sapphire and gold. HENRYK KOWALEWSKI/WIKIMEDIA COMMONS

BELOW: Only large, dense emission nebulae are visible from a city, even when you're using filters. The Lagoon Nebula (M8) is one of them. GERALD RHEMANN

OBJECTS FOR CITY OBSERVING

AFTER YOU SET UP your telescope under a light-polluted sky, here are a few objects in each season you can target. Wait for a clear, moonless night and start with a low-power eyepiece. Then increase the magnification if conditions warrant.

Winter	Spring	Summer	Fall
The Orion Nebula (M42), the Pleiades (M45), the Crab Nebula (M1), open cluster M35, the Owl Cluster (NGC 457), the Lion Nebula (NGC 2392)	Elliptical galaxy M87, the Sombrero Galaxy (M104), globular cluster M13, Bode's Galaxy (M81), the Cigar Galaxy (M82), the Beehive Cluster (M44)	The Ring Nebula (M57), the Double Double (Epsilon Lyrae), Albireo (Beta Cygni), the Lagoon Nebula (M8), globular clusters M22 and M5	The Andromeda Galaxy (M31), the Double Cluster (NGC 869 and NGC 884), the Blue Snowball (NGC 7662), globular cluster M15, Almach (Gamma Andromedae)

Hundreds more can keep you at the eyepiece for years.

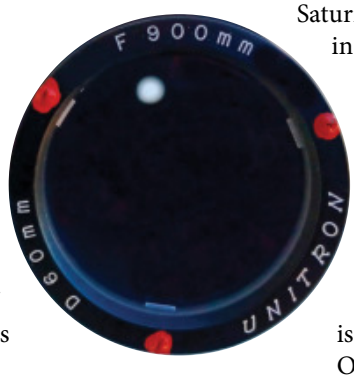
Open clusters are akin to double stars in that those with brighter members are easy to resolve with more aperture. Compact clusters are better suited for city observing than expansive ones. And bright skies can even bring out features within the clusters that would be otherwise hard to observe: I named NGC 2169 in Orion the "37 Cluster" when observing it from my backyard because when it is not overwhelmed with background stars, the shapes of the numbers 3 and 7 appear conspicuous.

While most globular clusters are better under dark skies, the closest are bright and easy to see in suburban skies. M3, M4, M5, M13, and M22 may be partially resolved into stars through a 6- to 8-inch telescope under urban skies.

Rule No. 5: Contrast is king

Photons are emitted from the millions of streetlights, business signs, spotlights, and other ways humans have devised to wrap us in light as much as possible. The effect, especially in humid air rich in microscopic water droplets, is that lights dance across the atmosphere, brightening the night.

Though the fuzzy glows of distant clusters, nebulae, and galaxies do the same thing from above, ground-based photons overwhelm the light from the sky, making them indistinguishable. But depending on the degree of light pollution, the densest parts of the brightest emission nebulae, like the Orion Nebula (M42), the Lagoon Nebula (M8), and the Omega Nebula (M17), may remain visible under city skies, even as the extensive nature of these star-forming regions is swamped.



The lens of this Unitron refractor has a focal ratio of f/15, much "slower" than most modern telescopes. But this f-ratio is a good one for targeting celestial objects from a city. MICHAEL E. BAKICH

Brighter galaxies fare well, too. Here, star density is what counts. Elliptical and lenticular galaxies, which are billions of older stars packed together, can remain visible even under bright skies. And although the arms of spiral galaxies are not visible under city conditions because, like emission nebulae, they are low-contrast features and get lost in the skyglow, their dense central hubs can be seen.

Rule No. 6: Filters help — a little

Light-pollution filters have been around for more than 40 years and are effective — but they have limits. They work by allowing certain wavelengths to pass through while blocking everything else: Ambient light pollution has a broad spectrum (white light), so only allowing a narrow band of light through means the view through the eyepiece will be darker. With dark-adapted eyes, ideally you should be able to see the object's light while the background light pollution is blocked. (If not, the only way around the problem is to use a larger telescope.)

The objects such filters help the most are planetary nebulae. These are the gas shells of dying Sun-like stars that emit a significant portion of light in green wavelengths. There are two factors in your favor: Human eyes are most sensitive to green light, and many planetary nebulae are compact, meaning their light is concentrated. As a result, you can see many of them under light-polluted skies. And for an even better look, try an Oxygen-III (OIII) filter.

Several bright planetaries populate the sky in every season. A few are even visible in small scopes. Among my favorites are the Lion Nebula (NGC 2392) in Gemini, the Ring Nebula (M57) in Lyra, the Cat's Eye Nebula (NGC 6543) in Draco, the Saturn Nebula (NGC 7009) in Aquarius, and the Blue Snowball (NGC 7662) in Andromeda. These are large enough to be visible at moderate magnification (around 100x) and look even better at 200x or more when atmospheric turbulence is minimal.

One of the inconsistencies when observing these dying suns is the brightness of the central star, the source of the nebula's glow. But some have bright central stars you might spot from the city. The Lion Nebula's central star glows at magnitude 10.5 and can be seen in a 2-inch telescope. The Cat's Eye's central star is slightly fainter at 11th magnitude.

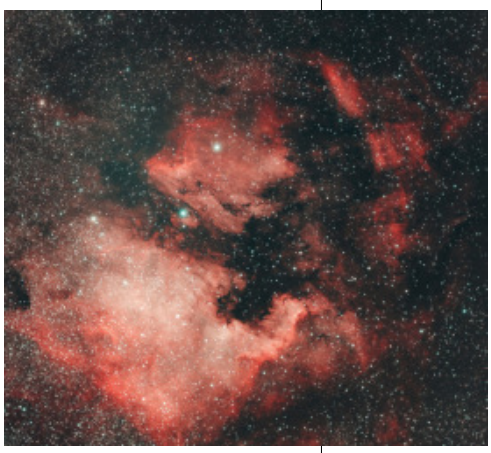
Oh, what a night!

Don't have time to drive to a dark site? Stargazing under the light dome of your community can still be rewarding. There are plenty of objects visible. Go-to telescopes allow you to easily find and focus on the objects you can see from your backyard — and invite your neighbors to take a peek.

Alan Goldstein *is a longtime observer of the skies and a frequent* Astronomy *contributor.*

Which filter should I use?

Capturing the right wavelengths makes a big difference in images.



The author captured images of the North America Nebula (NGC 7000) with a wideband filter (left) and narrowband filters. Notice how using a Hydrogen-alpha filter produced extra red in the image on the right.
MOLLY WAKELING (2)

BY MOLLY WAKELING
Molly is an avid astrophotographer active in STEM outreach. She has a Ph.D. in nuclear engineering.

The night sky is littered with galaxies, nebulae, and star clusters — if only we had eyes large enough to see them. Fortunately, cameras and telescopes can see what our eyes cannot.

It can be hard for a beginning astrophotographer to know which filters you should image a particular object with. But once you've been in this hobby long enough, you'll start to see some patterns emerge.

First, there are two classes of astrophotography filters: narrowband and wideband. Narrowband filters capture thin slices of the visible spectrum where elemental gases, such as hydrogen, oxygen, and sulfur, glow brightly. Wideband filters capture broad swaths; red, green, and blue (RGB) filters capture the primary colors separately; luminance (L or UV/IR) filters capture the whole visible spectrum; and light pollution (LP) filters also capture all visible light, but with some chunks blocked out to reduce the interference of either natural or human-made skyglows. On a one-shot color (OSC) camera, you'll use either an L/LP filter to pass all the light through the camera's pixel-scale color filters (the Bayer matrix — see my February 2026 column, "Camera face-off"), or you'll use multiple narrowband filters to capture emission, relying again on the Bayer matrix to separate the colors.

To determine which filter(s) to use, let's think about what's happening in the deep-sky targets we love. Stars emit all wavelengths of light, making them wideband sources. So, when you're going after star clusters, such as the Wild Duck Cluster (M11), wideband filters are the obvious choice. This extends to galaxies, such as the Whirlpool Galaxy (M51), which are just collections of stars and dust. Dark nebulae, such as the Seahorse Nebula (Barnard 150), show an absence of light because they block light from stars behind them, so these are also best done in wideband. For these kinds of targets, you should use L/LP and RGB filters (or just L/LP for OSC cameras).

There are two classes of astrophotography filters: narrowband and wideband.

On the other hand, emission and planetary nebulae glow primarily in narrowband wavelengths. Stellar nurseries such as the Orion Nebula (M42) display all three main emissions: hydrogen-alpha, doubly ionized oxygen, and ionized sulfur (Hα, OIII, and SII, respectively). However, planetary nebulae, such as the Ring Nebula (M57), result from Sun-like stars that are in their final stages of life. These stars aren't massive enough to have produced much sulfur in their lifetimes, so you can usually skip the SII filter. You'll want to use narrowband filters for these nebulae, and you can also take a little bit of data in RGB (or L/LP for OSC) to get nicely colored stars to add in, if you're able. You can image these nebulae in wideband, but you will get superior results in narrowband, with dramatically increased contrast and signal-to-noise ratio — especially if you live under heavy light pollution.

In nebulae such as the Trifid Nebula (M20) and the surroundings of the Pleiades (M45), their blue glow can look a lot like OIII emission. But don't be fooled! It's actually dust reflecting starlight — a reflection nebula.

For galaxies with significant active star formation, taking some Hα data can yield fruitful results. The Cigar Galaxy (M82) and the Fireworks Galaxy (NGC 6946) are examples that strongly benefit from adding Hα.

Imaging your target with the best-suited filters for its type can help you create an incredible image. Knowing a little about what you are shooting goes a long way, too. One of the best ways to figure out which filters you should use is to look up your target on AstroBin (https://app.astrobin.com) and see what others have used. But even if you don't have the same filters, capture it anyway! It's up there waiting to be seen.

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MARKETPLACE

Pulsar IGR J11014–6103 (lower right) shoots out a massive jet, its particles moving speeds 80 percent the speed of light — well over the 10 to 20 percent threshold to be considered relativistic. X-RAY: NASA/CXC/ISDC/L.PAVAN ET AL; RADIO: CSIRO/ATNF/ATCA; OPTICAL: 2MASS/UMASS/IPAC-CALTECH/NASA/NSF

Q OCCASIONALLY I SEE REFERENCES IN *ASTRONOMY* TO THE SPEED OF SOMETHING AS "SUPERSONIC." I'M HAVING TROUBLE RECONCILING THIS TERM WITH VELOCITIES TYPICALLY FOUND AMONG ASTRONOMICAL OBJECTS. WOULDN'T "RELATIVISTIC" BE CLOSER TO THE TRUTH? ANYTHING CLOSE TO SONIC SPEEDS IN EARTH'S ATMOSPHERE WOULDN'T COVER MUCH DISTANCE IN OUTER SPACE.

Peter Ianchiou
Tucson, Arizona

A One would certainly think that in the vast celestial playfields most objects would dart about at extreme velocities. Relativistic speeds are generally defined as anything above 10 to 20 percent the speed of light (which is denoted by the letter *c*). Since the speed of light equals exactly 299,792.458 kilometers per second, or about 186,282 miles per second, 0.1*c* equals approximately 18,628 miles (29,979 km) per second.

But macroscopic objects such as stars and planets move at speeds that are much slower than relativistic. Our own Sun is moving at a speed of 155 miles (250 km) per second relative to the galactic nucleus — just 0.083 percent of light speed. It doesn't cover much distance at such a speed; this is why it will require 225 million years or so to complete one orbit.

The fastest known star, a hypervelocity star called J0927–6335, is racing along at 1,389 miles (2,235 km) per second. While the ultra-speedy J0927–6335 would leave the comparatively lethargic Sun dust-coated and shamefaced, its impressive velocity is still equal only to 0.74 percent that of light, or 0.0074*c*. Thus, not even the fastest known star is moving at 1 percent the speed of light. And because no exoplanet yet discovered has attained an orbital velocity close to this value, we can also rule out the possibility that any planet's velocity could ever be described as relativistic.

However, the particles that comprise astrophysical jets are expelled from objects such as black holes, quasars, and neutron stars at relativistic speeds. For instance, the pulsar IGR J11014–6103 (associated with the Lighthouse Nebula in the constellation Carina) is blasting out a jet approximately 37 light-years long, which shoots its particles at a velocity nearly equal to 80 percent the speed of light. This velocity is most assuredly relativistic. Remember that in this instance, it is

particles — i.e., atoms — that have attained these velocities, not highly massive objects.

The term *supersonic* refers to speeds in excess of the speed of sound, but there's a catch: Sound needs a medium to travel through. And the speed of sound is different in different mediums. The speed of sound is different in water and air, and even then depends on factors like temperature and pressure. At sea-level pressure and a temperature of 68 degrees Fahrenheit (20 degrees Celsius), the speed of sound equals about 767 mph (1,186 km/h). But the speed of sound in the atmosphere of Mars or inside a nebula or molecular cloud in deep space is very different. In hot interstellar gas, the speed of sound can be hundreds of thousands of miles per hour.

WHILE THE ULTRA-SPEEDY J0927–6335 WOULD LEAVE THE SUN DUST-COATED AND SHAMEFACED, ITS IMPRESSIVE VELOCITY IS STILL EQUAL TO ONLY 0.74 PERCENT THAT OF LIGHT.

So in most cases, when astronomers call an object supersonic, their point of reference is the speed of sound in its local surroundings. A star moving through a nebula can be described as supersonic if it is moving faster than sound waves move through the interstellar gas around it. (Sometimes, we can easily see that this is the case because of the presence of a glowing bow shock, just like the shock that forms in front of a fighter jet as it breaks the sound barrier.) And while Earth's average orbital velocity of about 19 miles per second (30 km/s) is modest relative to typical sound and wave speeds in the interplanetary medium, the solar wind itself moves past Earth at around 250 miles per second (400 km/s). This flow is supersonic relative to the surrounding plasma (and the solar wind forms a bow shock upwind of Earth and its magnetic field).

However, these motions are nowhere near relativistic.

Edward Herrick-Gleason
Astronomy educator,
St. John's, Newfoundland and Labrador

Q | WHY DOES ONE SIDE OF THE MOON HAVE A LOT OF CRATERS, WHILE THE OTHER SIDE DOES NOT?

Stephen Loges
Brooksville, Florida

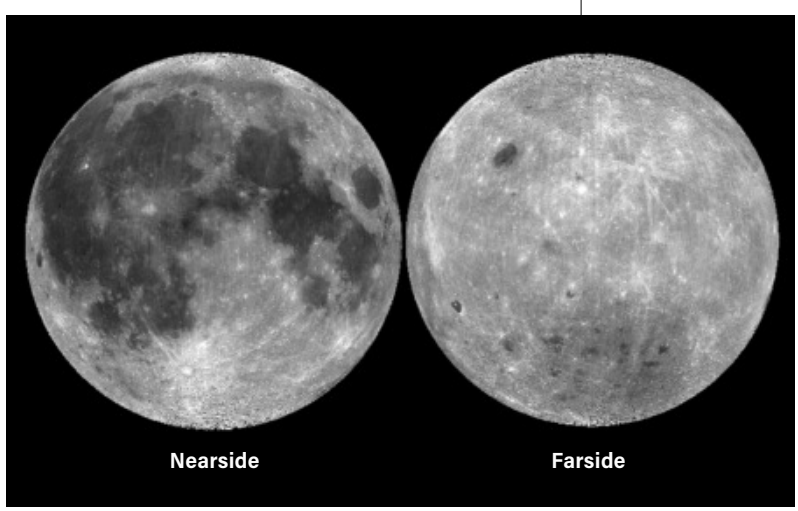
A | When the first photos of the Moon's farside were obtained, people usually expressed the difference between the back and the front in terms of "more craters on the back." It might be better to express it as "more lava plains on the front."

Like the craters on the farside, the lava plains (called maria) were formed by impacts — in fact, some of the largest the Moon has ever suffered — mostly early in its history. These impacts formed huge basins that penetrated to great depths where the Moon's materials were molten, so that lava, darker in tone than surface rocks, erupted and filled up the floors of all these structures.

Probably the largest of these is the North Polar Basin on the Moon's back side. It's so old that its rim features and lava floor have been mostly destroyed by later craters. A similarly old, eroded giant basin is Oceanus Procellarum on the front side. It was later almost demolished by the more recent, but still early, giant Imbrium impact basin, whose samples date at 3.8 billion to 3.9 billion years old — only 600 million years after the formation of the solar system's planetary bodies. The prominent Mare Imbrium lavas flooded Imbrium's floor mostly about 2 billion to 3.8 billion years ago — though some interesting sampled lava eruptions there have been estimated to have ages as young as 1 billion years.

Those ancient lava plains suggest it's possible that the Earth-facing side actually got more of the large impact basins than the farside in those first few hundred million years. The Moon was closer to Earth in the early millennia, and Earth-passing asteroids might have been deflected by Earth's gravity and attracted by the Moon's gravity, crashing into the Earth-facing side of the Moon.

William K. Hartmann
Senior Scientist Emeritus,
Planetary Science Institute, Tucson, Arizona



Views of the Moon's nearside and farside were taken by NASA's Clementine in 1994. The orbiter used the same camera and filter for both sides, highlighting their differences. NASA

SEND US YOUR QUESTIONS

Send your astronomy questions via email to **askastro@astronomy.com**. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

1. AURORA ON ICE
The Northern Lights reflect off of Iceland's Fjallsárlón Glacier Lagoon on Oct. 2, in this shot captured with a Canon mirrorless camera and 14mm lens. The exposure was 8 seconds at f/2.8 and ISO 2500. ▪ ***Felipe Menzella***

2. DWARF GALAXY PHOTOBOMB
Comet Wierzchoś (2024 E1) put on a nice show for Southern Hemisphere binocular observers and imagers, featuring multiple tails. Here, it slides by the dwarf galaxy PGC 3589 in Sculptor on Feb. 14. The imager used a 12-inch f/3.6 scope to take LRGB exposures of 20, 9, 9, and 9 minutes, respectively. ▪ ***Gerald Rhemann***

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3. NEXT-DOOR NEBULA
NGC 1769 is an emission nebula that lies not in our home galaxy but in the Large Magellanic Cloud, some 160,000 light-years away. This nebula is also part of the larger NGC 1763 star-forming complex. The imager used a 17-inch scope to capture 44 hours of SHORGB data. ▪ ***Nicholas Clarke***

4. DEATH VALLEY LIGHTS
Two rivers of light form a V in the sky above Death Valley in this image — the zodiacal light and the Milky Way. The photographer used an astromodified Canon DSLR to capture five subexposures of 30 seconds each at f/2.8 and ISO 3200. ▪ ***Chris Cook***

SEND YOUR IMAGES TO: readergallery@astronomy.com.
Please include the date and location of the image, your mailing address, and complete photo data: telescope, camera, filters, and exposures.

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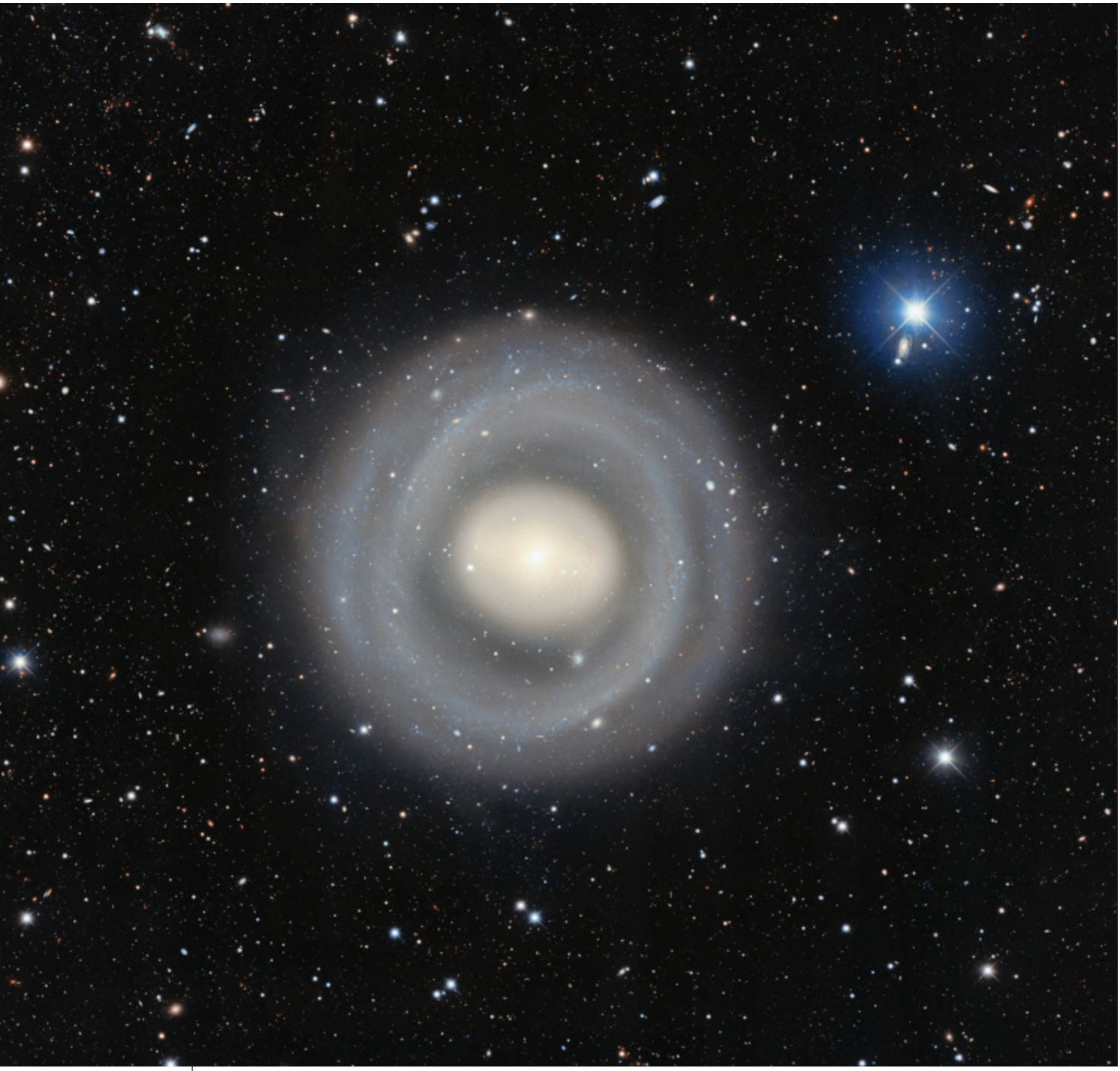

A RIVER RUNS THROUGH IT

The galaxy you see here has an identity crisis. Scottish astronomer James Dunlop discovered it in 1826, and John Dreyer included it as the 1,291st entry in his *New General Catalogue*. Ten years after Dunlop's sighting, English astronomer John Herschel stumbled across the same object and, not knowing of Dunlop's observation, christened it NGC 1269. Whichever moniker you prefer, the 9th-magnitude object presents a stunning example of a nearly face-on barred lenticular galaxy. It possesses a pronounced bar-shaped central bulge surrounded by an inner and outer ring. The rings likely formed when a smaller galaxy merged with NGC 1291. The collision stripped the resulting galaxy of its interstellar gas, so it no longer creates many stars. NGC 1269 lies 33 million light-years from Earth in the constellation Eridanus the River. DARK ENERGY SURVEY/DOE/FNAL/DECAM/CTIO/NOIRLAB/NSF/AURA

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August 2026
Venus stands alone

Although the early evening sky boasts only one naked-eye planet, quality more than makes up for the lack of quantity. **Venus** attains a splendid peak when it reaches greatest elongation Aug. 15. It then lies 46° east of the Sun and stands 30° high in the west an hour after sundown. The planet shines brilliantly at magnitude –4.4, making it the sky's brightest object after the Sun and Moon.

Venus crosses from Leo into Virgo on Aug. 1 and spends the rest of the month within the Maiden's confines. By the end of August, it lies just 2° west of Virgo's brightest star, 1st-magnitude Spica.

You definitely should follow Venus through your telescope this month. The planet's disk grows noticeably larger while its phase diminishes in concert. On Aug. 1, Venus measures 21" across and appears 56 percent lit. On the 31st, the planet spans 30" and the Sun illuminates 39 percent of its Earth-facing hemisphere.

By late evening, another stunning solar system world comes into view. **Saturn** rises in the east a bit before 11 P.M. local time in early August and some two hours earlier by month's end. The ringed planet resides among the background stars of southern Pisces the Fish, just across the border from Cetus the Whale.

Even a small telescope reveals the planet's lovely ring system. In mid-August, you'll see the planet's 19"-diameter disk surrounded by a ring system that spans 43" and tilts 9° to our line of sight. The sharpest views will come as Saturn climbs higher in the sky after midnight. Also keep an eye out for Saturn's brightest moons. Eighth-magnitude Titan shows up through any scope, while the 10th-magnitude trio of Tethys, Dione, and Rhea appears in 10-centimeter and larger instruments.

You'll have to wait a while — or plan to get up early — to see the next planet. **Mars** continues to trek eastward relative to the starry backdrop, moving from eastern Taurus the Bull into central Gemini the Twins. By 5 A.M. local time at the end of August, Mars forms a pretty isosceles triangle with Gemini's two brightest stars, Castor and Pollux. At magnitude 1.3, the planet closely matches the stellar duo. Although it's easy to spot, Mars shows a featureless disk spanning 5" when viewed through a telescope.

Keen observers should try to spot **Mercury** in early August. The innermost planet reaches greatest elongation Aug. 2, but it then lies just 19° west of the Sun and hangs low in the east-northeast during morning twilight. A telescope reveals Mercury's crescent-shaped disk, which measures 8" across. The planet disappears in the Sun's glare by midmonth on its way to superior conjunction Aug. 27.

Jupiter also plays hide-and-seek with the Sun. You should be able to spot the planet a half-hour before sunrise at the end of August. It shows up in bright twilight only because it shines brilliantly at magnitude –1.8. Jupiter's visibility suffers from the shallow angle of the ecliptic to the eastern morning horizon at this time of year. Better views will come this spring when the planet appears farther from the Sun.

A nearly total lunar eclipse occurs Aug. 28. Residents across South America can watch the entire event. The partial phase runs from 2h33m UT to 5h52m UT and peaks at 4h13m UT. At maximum, 93 percent of the Full Moon lies in Earth's umbral shadow, and viewers should see Luna's southern half take on a reddish glow.

A total solar eclipse also takes place this month, on the 12th, but the narrow path of totality only touches the Northern Hemisphere. To see totality from solid ground, you'll have to travel to either Iceland or Spain.

The starry sky

Late winter is one of the best times of year for Southern Hemisphere stargazers. On a moonless night away from the lights of the city, the Milky Way looks truly magnificent. One of the most recognizable constellations, Scorpius, passes nearly overhead in the early evening. Be sure to take some time to explore the Scorpion with your naked eye, binoculars, or a telescope.

Scorpius is one of the 88 constellations the International Astronomical Union officially recognized in the 1920s. Although that may seem like a lot — after all, they do cover the entire sky without any gaps or overlap — many earlier observers attempted to introduce more. A little-known one occupies a small area in the constellation Ophiuchus the Serpent-bearer, which lies due north of Scorpius.

Lithuanian astronomer Marcin Poczobutt (1728–1810) introduced the diminutive Taurus Poniatovii in 1777, creating the sky's second bull. Poczobutt, the director of the Royal Observatory in the capital city Vilnius (which was then called Vilna), wanted to honor King Stanislaw Poniatowski (1732–1798), Poland's last king.

Although the constellation's pattern is certainly obscure, the little V-shaped group of stars that marks the bull's head is easy to find. The stars have the Flamsteed numbers 66, 67, 68, 70, and 73 Ophiuchi; 67, 68, and 70 create a small, easy to see triangle not far from Ophiuchus' border with Serpens. The pair 71 and 72 Oph forms one of the bull's horns while 4 Aquilae marks its right front foot and Theta (θ) Serpentis the left front foot.

Sadly for Taurus Poniatovii (and the king), the constellation did not survive. However, a rendition of it appears in a set of constellation cards published in London in 1824.

STAR DOME

HOW TO USE THIS MAP

This map portrays the sky as seen near 30° south latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

9 P.M. August 1
8 P.M. August 15
7 P.M. August 31

Planets are shown at midmonth

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

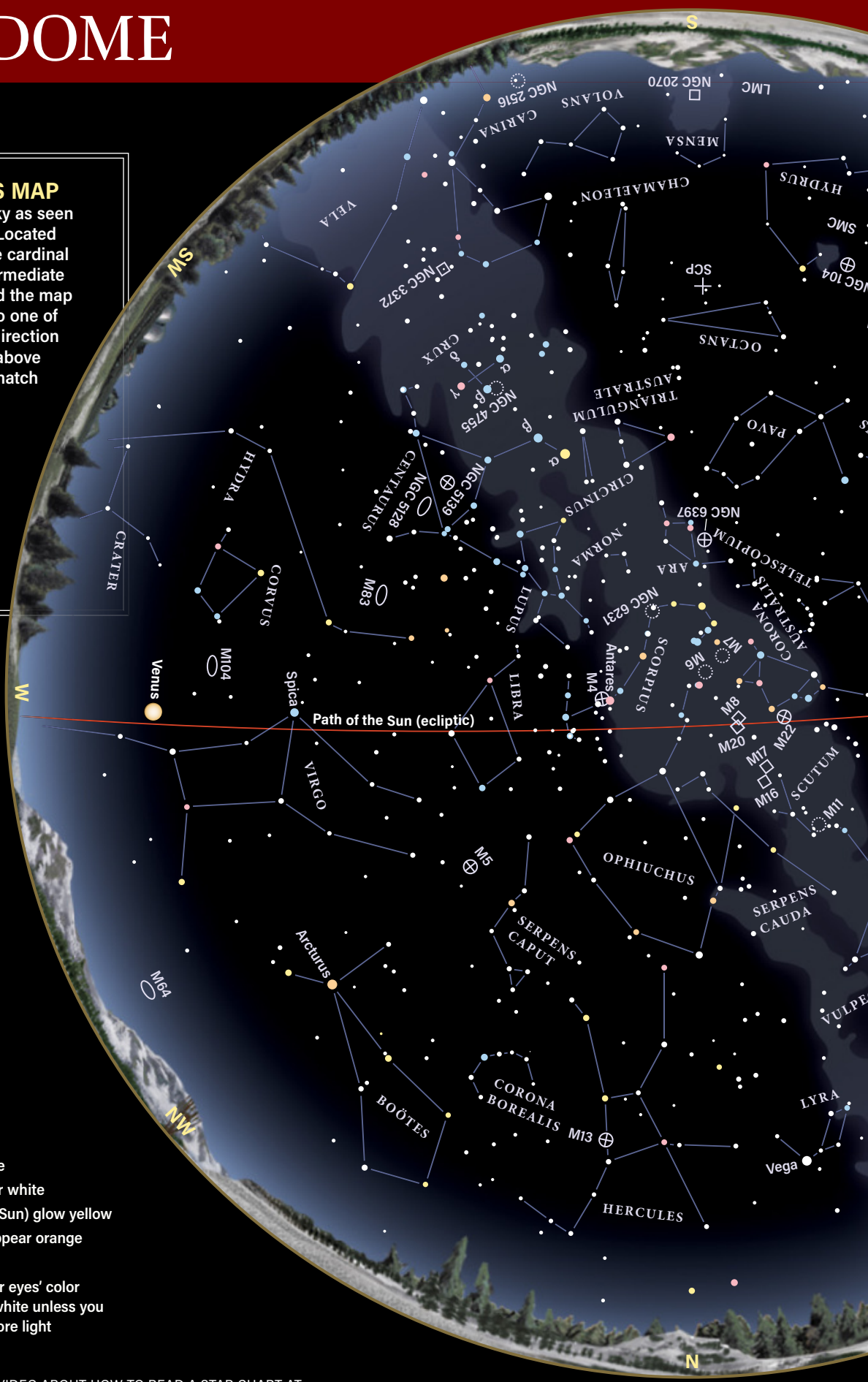
STAR MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light



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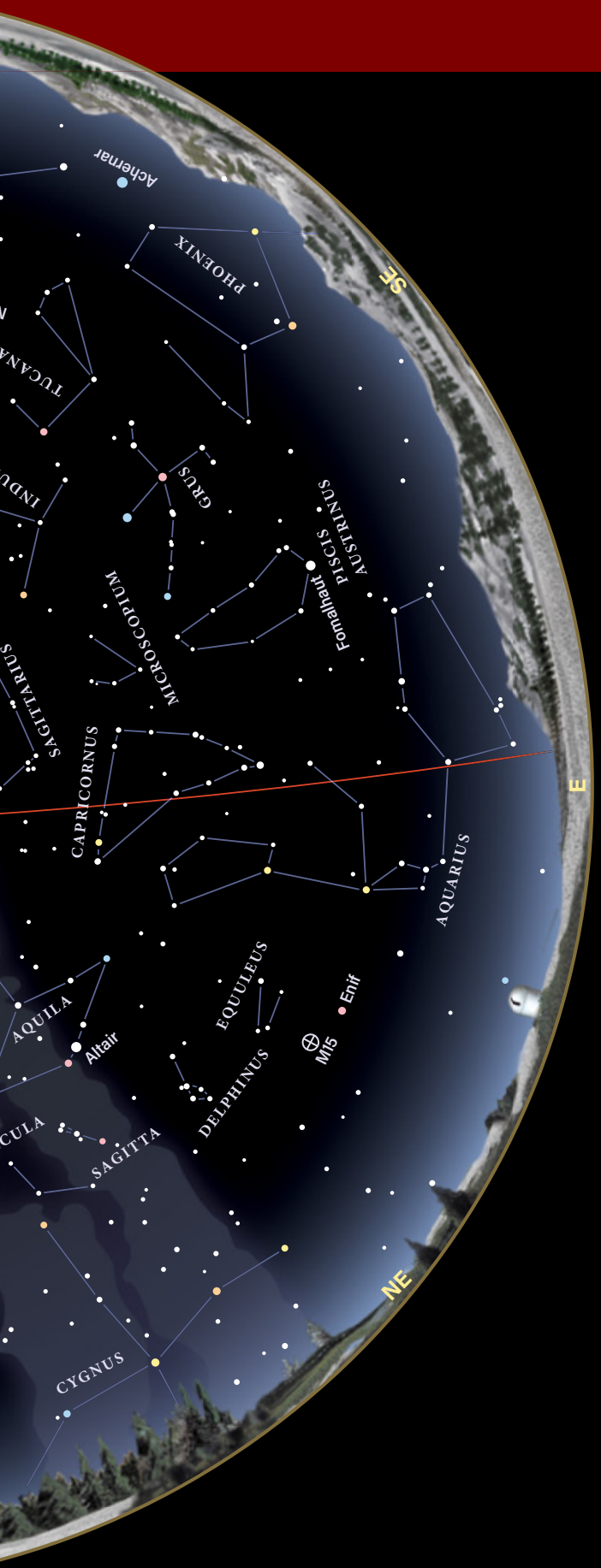

AUGUST 2026

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

2 Mercury is at greatest western elongation (19°), 8h UT

3 The Moon passes 5° north of Neptune, 8h UT

4 The Moon passes 7° north of Saturn, 4h UT

6 Last Quarter Moon occurs at 2h21m UT

Mercury passes 8° south of Pollux, 4h UT

7 The Moon passes 5° north of Uranus, 17h UT

9 The Moon passes 4° north of Mars, 6h UT

10 The Moon is at perigee (363,284 kilometers from Earth), 11h18m UT

11 The Moon passes 2° north of Mercury, 13h UT

12 New Moon occurs at 17h37m UT; total solar eclipse

15 Venus is at greatest eastern elongation (46°), 6h UT

Mercury passes 0.6° north of Jupiter, 9h UT

16 The Moon passes 2° south of Venus, 9h UT

20 First Quarter Moon occurs at 2h46m UT

21 The Moon passes 0.6° south of Antares, 5h UT

22 The Moon is at apogee (404,642 kilometers from Earth), 8h21m UT

27 Asteroid Pallas is stationary, 12h UT

Mercury is in superior conjunction, 17h UT

28 Full Moon occurs at 4h19m UT; partial lunar eclipse

Asteroid Metis is at opposition, 14h UT

Asteroid Vesta is stationary, 22h UT

30 The Moon passes 5° north of Neptune, 13h UT

31 The Moon passes 7° north of Saturn, 8h UT

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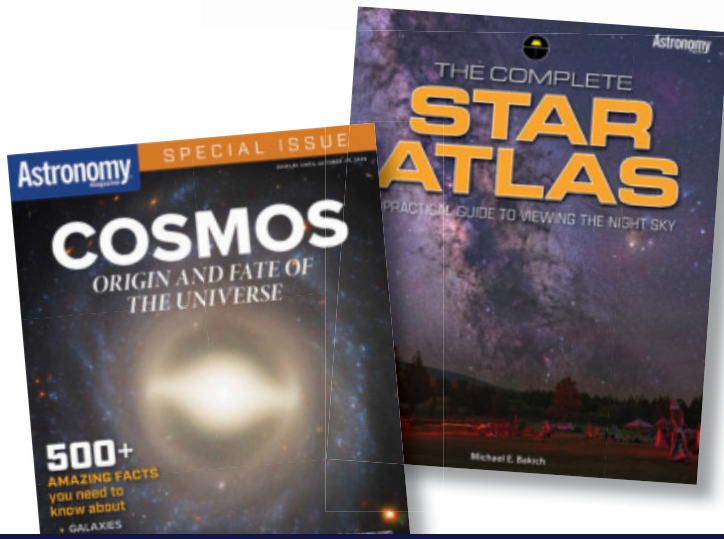

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